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Research Note 81-30

UTILIZATION OF HUMAN RESOURCES DATA IN BATTLEFIELD AUTOMATED SYSTEMS

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U. S. Army

Research Institute for the Behavioral and Social Sciences

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This volume reports on how well human resources data (HRD) have been utilized in the development cycles of U.S. Army command, control, communications, and intelligence (C^3I) systems. The incorporation of human resource issues was examined in the development cycles of two C^3I systems: the Tactical Operations System (TOS) and the Stand-Off Target Acquisition System (SOTAS). The study concludes that effective use of HRD can be brought about only with early management recognition of the problems and with an appropriate focal point in the managerial team structure.

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UTILIZATION OF HUMAN RESOURCES DATA IN BATTLEFIELD AUTOMATED SYSTEMS

BRIEF

This volume reports on how well human resources data (HRD) have been used in the development of US Army command, control, communications, and intelligence (C^3I) systems. It makes recommendations for increasing the utility of such data. The findings and recommendations reported here come from a study carried out with the following objectives:

- 1) To examine the Army system development cycle from the proponent's point of view.
- 2) To identify points within the cycle where human resources data would have a pronounced impact on operational concepts, system definition requirements, training requirements, doctrine development, and other aspects of the proponent's role.
- 3) To identify ways of improving the development and use of human resources data. and
- 4) To identify the technological gaps in the problem of incorporating human resource data in the system development cycle.

The use of human resources data was studied in the development cycles of two C^3I systems: the Tactical Operations System (TOS) and the Stand-Off Target Acquisition System (SOTAS). The XM1 Abrams Main Battle tank was also examined in order to provide a comparison between weapon system development and C^3I system development.

Computer integrated tactical data systems

Findings:

The three systems examined were found to exhibit widely different results in the effective use of human resources data in the system development. In the TOS program, human resource issues were assigned a low priority relative to other problems, so that there never existed a focal point in the system development team for addressing such issues. By contrast, the SOTAS program set high management priority on human resource issues at the very outset and retained as the focal point for such issues a Deputy Project Manager (DPM), assisted by a team of behavioral scientists. The SOTAS program was able to resolve certain difficult personnel and training problems because these problems received early attention in the development cycle. The third program, that of the XMI tank, has had mixed success in using human resources data in its development. Because there was considerable management

interest in the human factors engineering of tank operations, this area represented highly effective use of HRD. But in three other areas: organizational maintenance, DS/GS maintenance, and logistical support, delayed management attention has resulted in less than effective application of human resources data.

Throughout its 23 years under development, the TOS program has not had any human factors personnel or applied psychologists familiar with automated data processing systems on the system design team. Human resource issues were largely excluded from consideration until it came time to evaluate the system. Human resource data has not been adequately incorporated in the system development notwithstanding the fact that ARI (and its predecessor BESRL) has provided support in terms of human factors research. Starting in 1966, BESRL provided support in both the field tests and laboratory approaches to TOS development. Starting in 1967 - and continuing through 1977 - ARI conducted extensive laboratory analysis of tactical information processing under the Simulated Tactical Operations System (SIMTOS) program. Starting in 1970, ARI also conducted a number of research projects on the tactical data entry process. These research results have not been effectively used in the TOS program. This is largely because there has been no focal point in the program for human resources data.

The SOTAS program, on the other hand, represents very effective employment of human resources data. It has incorporated human resource issues since the initial milestone review. The Project Manager (PM) recognized early that several complex human engineering problems had to be solved before SOTAS could become an operationally effective system. The SOTAS development program began with, and continues today with, a project management structure that effectively addresses the human factors and human engineering issues in the C^3I system. Because the program represents a successful example of the utilization of HRD, the details of what was done and when it was done provide a valuable case study.

The XM1 Abrams Tank Program was reviewed in order to compare weapon system development with C^3I system development. This program exhibits a spotty picture regarding the use of human resource issues. High management priority was given to the human factors engineering insofar as tank operations were concerned, but there was delayed recognition of the personnel and training requirements for organizational maintenance, DS/GS maintenance and logistical support.

All three case studies suggest that the effective use of human resources data in the system development cycle is dependent on the amount of management emphasis on these issues and the early recognition of all the specific human factors problems in the system.

Conclusions and Recommendations:

The central conclusion is that the key to the successful use of human resource data in system development is the early recognition by the project management of the relevant human factors problems and human resource requirements and then the establishment of a management structure to provide a focal point for these issues. In order to do this management must be shown the direct relevance of human resource issues on system effectiveness. This means that a quantitative link must be developed between human resources and battle outcome.

The following two recommendations for further research constitute a program to establish the quantitative link:

- Development of a Human Resources Data Base. This data base will relate human aptitudes and basic skills to task performance, training requirements, and personnel requirements.

- Development of Models relating Human Performance on Battle Outcome. These models will provide the tools for showing the quantitative link between human resources and system effectiveness.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I
INTRODUCTION

This final report reviews the utilization of human resources data (HRD) in the development of US Army command, control, communications, and intelligence (C^3I) systems and makes recommendations for increasing the utility of such data. The study was conducted under research contract MDA903-79-C-0695, funded by the US Army Research Institute for the Behavioral and Social Sciences (ARI). The objectives of the study were to examine the Army system development cycle from the point of view of the system proponent; to identify points within the cycle where human resources data would have the most impact on operational concepts, system definition requirements, training requirements, doctrine development, and other aspects of the proponent's role; to identify available methods, procedures, and practices for providing and using human resources data; and to identify technological gaps requiring research and development to support the use of human resources data by Army systems proponents.

Efforts were directed at identifying points in the system development cycle for the Tactical Operations System (TOS) and the Stand-Off Target Acquisition System (SOTAS) when the system proponent used or could have used human resources data and associated methods. The XM1 Abrams Main Battle Tank was examined to compare and contrast weapon system development with C^3I system development. The emphasis of this report is on the types of data or analyses used successfully or, if not used, which might have been used beneficially.

Acronyms are used frequently throughout the report and are fully identified the first time they are used. A list of these acronyms and other abbreviations is presented in Appendix C.

1.1 PROBLEM STATEMENT

In its search for greater combat effectiveness and increased combat capability, the US Army has made significant strides in harnessing technology to improve mobility, firepower, communications, logistic support, and intelligence collection. This effort has produced new hardware, new system designs, new organizational and operational concepts, and new doctrine for the employment of functional components of the tactical force. These developments have

been extended to weapon systems which include automatic data processing in the closing of the target engagement loop. There has been, however, little corresponding improvement in the development of automated battlefield systems of the decision-aiding variety, such as TOS. Despite more than 25 years of applying extensive technological resources to this problem, there has been a fundamental lack of success in fielding an automated tactical command and control (C^2) system in the Army or any other service.

It has long been recognized that the development of systems must take into account the characteristics of the expected user. As a result, an extensive body of knowledge has been accumulated on the description, attributes, and skills of users. Much of this knowledge has been incorporated into various "human factors" handbooks [1, 2, 3, 4, 5, 6] and subsequently utilized by system designers in hardware design and development. However, the emphasis during the development of automated battlefield systems has been narrowly focused on equipment rather than on operator performance.

Various explanations can be offered for this relatively narrow focus, but all eventually lead to the conclusion that existing

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[1] A. Chapanis, W. R. Garner and C.T. Morgan, Applied Experimental Psychology: Human Factors in Engineering Design. New York: Wiley, 1949.

[2] A. Chapanis, Research Techniques in Human Engineering (Revised Ed.), Baltimore: John Hopkins Press, 1965.

[3] R.M. Gagne (Ed.), Psychological Principles in System Development. New York: Holt, Rinehart and Winston, 1962.

[4] H.W. Sinaiko and E. P. Buckley, Human Factors in the Design of Systems. Naval Research Laboratory (Washington, D.C.), Report No. 4996, August 29, 1957.

[5] H. P. Van Cott and R. G. Kinkade (Eds.), Human Engineering Guide to Equipment Design (Revised Ed.). Washington, D.C.: U.S. Government Printing Office, 1972.

[6] W. E. Woodson, Human Engineering Guide for Equipment Designers. Berkeley and Los Angeles: University of California Press, 1954.

handbooks or guidelines generally have been unavailable to or uninterpretable by the typical automated system designer. Accordingly, the designer has been without adequate information to address other aspects of human resources and their interaction with the system. For example, in well-researched areas, such as keyboard design and certain physical properties of displays, handbooks [7, 8, 9, 10] provide the system designer detailed guidelines on human attributes to design consoles or other interface devices and, in some cases, to select appropriate off-the-shelf input/output devices. However, available design guidelines become sparse, contradictory, or nonexistent when considering design trade-offs that must be made concerning more central issues such as training, task allocation among users and machines, user information requirements, decision aids, and interactive dialogue techniques. So it is not surprising that even though the designer may recognize that many design decisions have human resources overtones, he will narrowly focus on the man/machine interface--not on determining the functional role of humans within the context of the total system.

The implication is that human factors analysis has been used primarily to determine the "how" of the interface and not to answer the more fundamental questions of "who," "where," and "why" during system design. Answers to the latter questions would allow the system designer to integrate considerations for operators and machines simultaneously, rather than to design machines and then attempt to fit operators into the system. Accordingly, it is imperative that the system designer incorporate answers to these questions and their associated personnel impacts if the Army is to achieve any significant progress in the development of automated battlefield systems. In order to accomplish this goal, systems designers must be given adequate guidelines as to when and how to consider these questions to effectively use human resources data in the system development cycle.

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[7] E. J. McCormick, Human Engineering. New York: McGraw-Hill, 1957.

[8] C. T. Morgan, J. S. Cook, A. Chapanis, and M. W. Lund, Human Engineering Guide to Equipment Design. New York: McGraw-Hill, 1963.

[9] C. F. Schmid, Handbook of Graphic Presentation. New York: Ronald Press, 1954.

[10] Tufts College, Institute of Applied Experimental Psychology, Handbook of Human Engineering Data (2nd Ed.). Office of Naval Research, Special Devices Center, NavExos P-643, Technical Report No. SDC 199-I-2, 1952.

Based on the foregoing, the research problem here is to examine the Army system development cycle (as it relates to C^3I systems) from the point of view of the system proponent to identify:

- Points within the cycle where human resources data would have the greatest impact on operational concepts, system definition requirements, training requirements, doctrine development, and other aspects of the proponent's role--with special emphasis on improving the determination of an optimal division of labor among users and machines in decision-aiding systems

- Available methods, procedures, and practices for providing and using human resources data--to facilitate trade-offs among manpower/training/hardware/software/system design considerations

- Potential improvements in the use of human resources data in the development of C^3I systems

- Technological gaps requiring research and development to enhance the utilization of human resources data by Army system proponents.

Before proceeding further, it will be useful to review briefly the Army major system development cycle and to discuss the current regulations concerning human resources data and their relevancy to cycle.

1.2 ARMY DEVELOPMENT CYCLE

A brief review of the Army system development cycle follows to provide a basic framework for understanding the responsibilities of the major agencies involved. A more detailed discussion is presented in Appendix B.

Army Regulation (AR) 1000-1[11] establishes the basic policy for the acquisition of major systems and is based upon the guidance of

[11] AR 1000-1, Basic Policies for System Acquisition, April 1, 1978.

the Office of Management and Budget (OMB) Circular A-109 and Department of Defense Directive (DoDD) 5000.1 and Instruction (DoDI) 5000.2.[12]

Figure 1-1 (reproduced from AR 1000-1) summarizes the development cycle for major systems and indicates the four major milestones. At each of these milestones, the status of the system is reviewed and a decision made to advance to the next stage of the development process, repeat all or portions of the previous phase, or terminate the process.

The Army has divided the responsibilities of the system development cycle into four major areas: the proponent (or user's representative), the materiel developer, the operational tester, and the logistician. Guidance, coordination, and Department of Defense (DoD) interface is provided by the Department of the Army (DA) staff.

1.2.1 PROPONENT

The system proponent, or user's representative, is the US Army Training and Doctrine Command (TRADOC). TRADOC plays a major role in the development process and its major responsibilities include:

- Preparing, in coordination with the materiel developer and logistician, the Mission Element Needs Statement (MENS), which justifies initiation of a new major system acquisition
- Preparing, in coordination with the materiel developer and logistician, the Required Operational Capability (ROC) and associated documentation
- Conducting concept evaluation force development tests and experiments and participating in force development test and evaluation (FDTE) conducted by others

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[12] AR 1000-1 is currently being revised to reflect recent modifications to DODD 5000.1 and DoDI 5000.2. These revisions are expected to fully incorporate the provisions of OMB Cir. A-109.

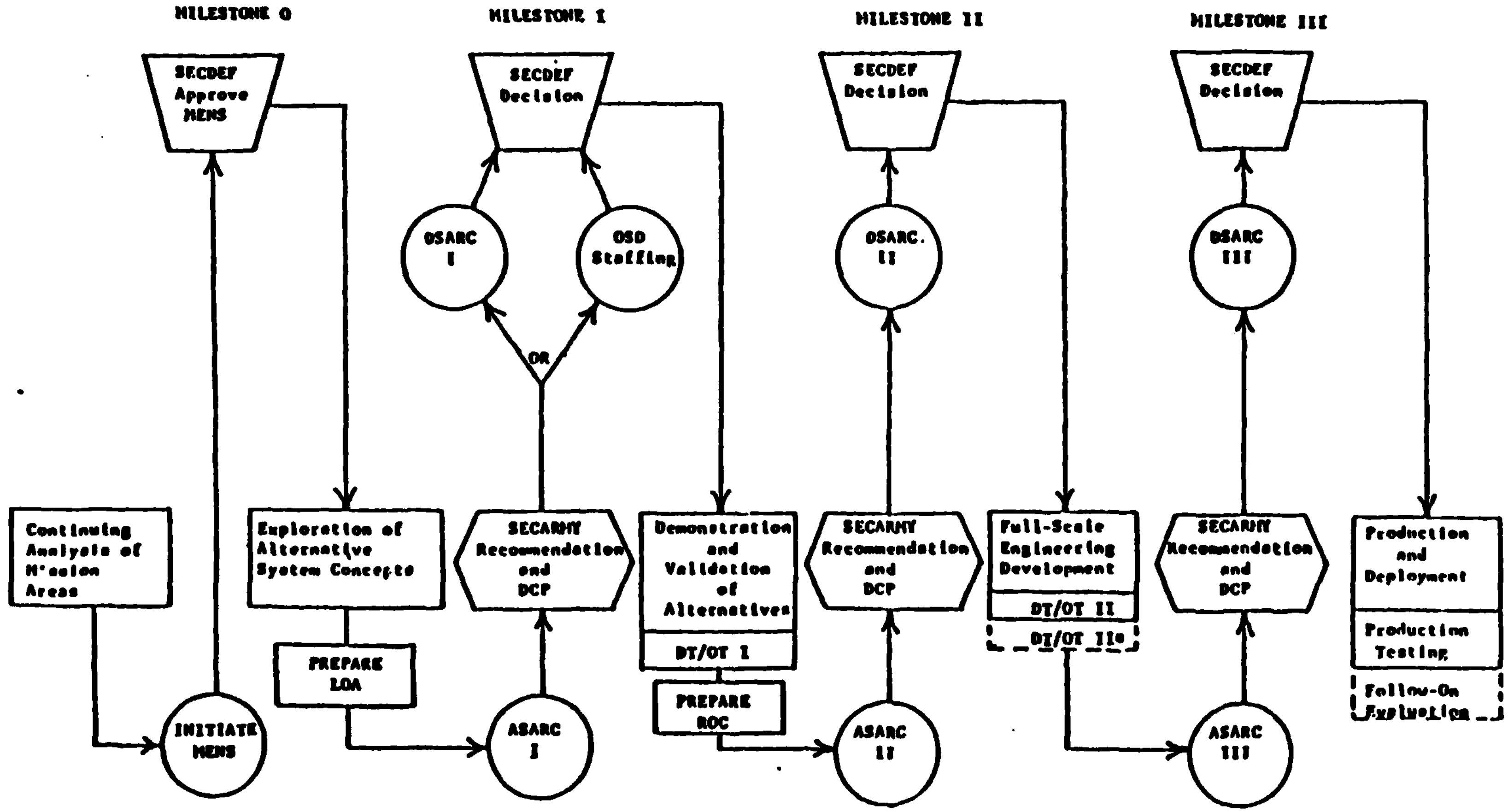

FIGURE 1-1. MATERIEL ACQUISITION PROCESS FOR MAJOR SYSTEMS

- Monitoring developmental tests (DTs); participating in operational testing of selected materiel systems; and planning, conducting, and evaluating operational tests of other materiel systems

- Assessing a proposed materiel system for training implications and planning for establishing the training programs to support its ultimate deployment

- Determining the requirement for simulators and training devices early in the development cycle

- Assessing, in coordination with the system developer and logistician, the logistical support requirements of materiel systems under development

- Assessing the personnel subsystem proposed to support the materiel being fielded for Military Occupational Specialities (MOS) implications and planning for personnel acquisition and training.

1.2.2. Materiel Developer

The Materiel Development and Readiness Command (DARCOM) is the Army's materiel developer. For each major system a Project Manager (PM), chartered by the Secretary of the Army and assigned to a commodity command, acts as DARCOM's principal agent. The PM is responsible for developing a total program acquisition strategy. His primary concern is the development of the system, on time and within funding constraints. Other major responsibilities include the following:

- Logistic support planning

- Preparing baseline cost estimates in accordance with the work breakdown structure

- Preparing the outline acquisition plan, acquisition plan, resident training plan, and new equipment training plan

- Developing independent parametric cost estimates for the system
- Producibility engineering and planning
- Identifying long lead time component requirements
- Formulating the initial qualitative and quantitative personnel requirements information (QQPRI) and MOS decisions
- Awarding the contract for low rate initial production and initial production facilities
- Developing of technical manuals (TMs)
- Coordinating with the operational tester for required tests, independent evaluation reports, and appropriate updates.

As the focal point for scheduling and funding, the PM is, in practice, the single most powerful voice in the system acquisiton cycle.

1.2.3 Operational Tester

The Army's independent agent for operational test and evaluation is the US Army Operational Test and Evaluation Agency (OTEA), an agency of the Office of the Chief of Staff, Army (CSA), generally working directly with the Vice Chief of Staff, Army (VCSA).

OTEA is responsible for planning, managing, and independently evaluating all operational tests (OTs) for all major systems. OTEA will generally assign the conduct of an OT to a TRADOC test agency with participants from a field unit.

1.2.4 Logistician

The logistician for the Army development cycle is the US Army Logistics Evaluation Agency (LEA), an agency of the DA Deputy Chief of Staff for Logistics (DCSLOG). LEA's activities are, however, confined almost entirely to review. Logistics requirements are generally set by TRADOC and logistics planning is primarily the responsibility of the PM.

1.3 HUMAN RESOURCES GUIDANCE IN THE DEVELOPMENT CYCLE

AR 1000-1 also sets forth policy on human factors engineering, in addition to policy on safety and health, as follows:

- The number and skill levels of personnel required and human engineering factors will be included as constraints in system design. Other logistic constraints, such as capability and availability of existing test equipment, transportability, and maintenance facilities, will be included in applicable program plans.

- Materiel systems developed or acquired by the Army must be supportable by the personnel skills available. Timely training support must be provided to sustain operational development of materiel and personnel support planning will consider the growing number of women in the Army. Integration of the human element and system will start with initial concept studies, be progressively refined as the system progresses, and be documented in the logistic support analysis (LSA). LSA documentation will form the basis for personnel authorization criteria, personnel selection and training, development of training devices and simulators, and planning related to human factors. Human factors considerations will be validated during DT/OT as part of the system support package.

The above extracts from Army regulations certainly indicate that it is Army policy to integrate human resources data into the system development cycle in all of its phases from concept development through demonstration and validation to full scale engineering development and includes operator/maintenance personnel and training requirements. The regulations even provide for the identification of human factors research required to support the training requirements and the operational concept. In fact, the regulations would seem to provide an adequate basis for using human resources data in trade-off analyses, interrelating system effectiveness with design parameters, qualitative and quantitative personnel requirements, and learning/training dimensions to support early decisions.

It is pertinent, then, to inquire if the integration, or lack thereof, of human resources data in the Army has affected the somewhat less than successful development of automated battlefield systems, such as TOS for which an operations concept was enunciated more than 25 years ago, but which has yet to be fielded. The case studies on TOS, SOTAS, and XM1 do provide insight into the dilemma and are addressed in Section II.

Another clue can be found in the regulations themselves in that they tend to place a rather narrow interpretation on "human engineering" data as it applied to concept development and system design. For example, AR 602-1 states that task sequences developed originally for personnel-materiel task allocation and determination of personnel compatibilty will be used to the maximum extent feasible in:

- The determination of personnel-materiel interface requirements (displays, controls, test points, and maintenance tasks)
- The development of new or revised MOS or duty descriptions
- The development of training programs, training equipment, and standards for training
- The development of a product improvement program
- The assessment of human performance reliability. The personnel data base will be brought up to date whenever affected by design or configuration changes. HFE will be applied to planning and making changes in missions, doctrine, organizations, and equipment to avoid personnel-materiel incompatibility.

The interesting fact is that, while these are all valid applications of task sequencing for human factors considerations, the fundamental application of human resources data to an initial determination of the task sequence is not even mentioned. This suspicion is confirmed by examining Figure A-1 of that regulation, reproduced herein as Figure 1-2, which purports to show personnel considerations in system effectiveness. Again, the emphasis is on the narrow question of optimizing a personnel-materiel interface that has already been defined--not on determining where the interface should be in the first place.

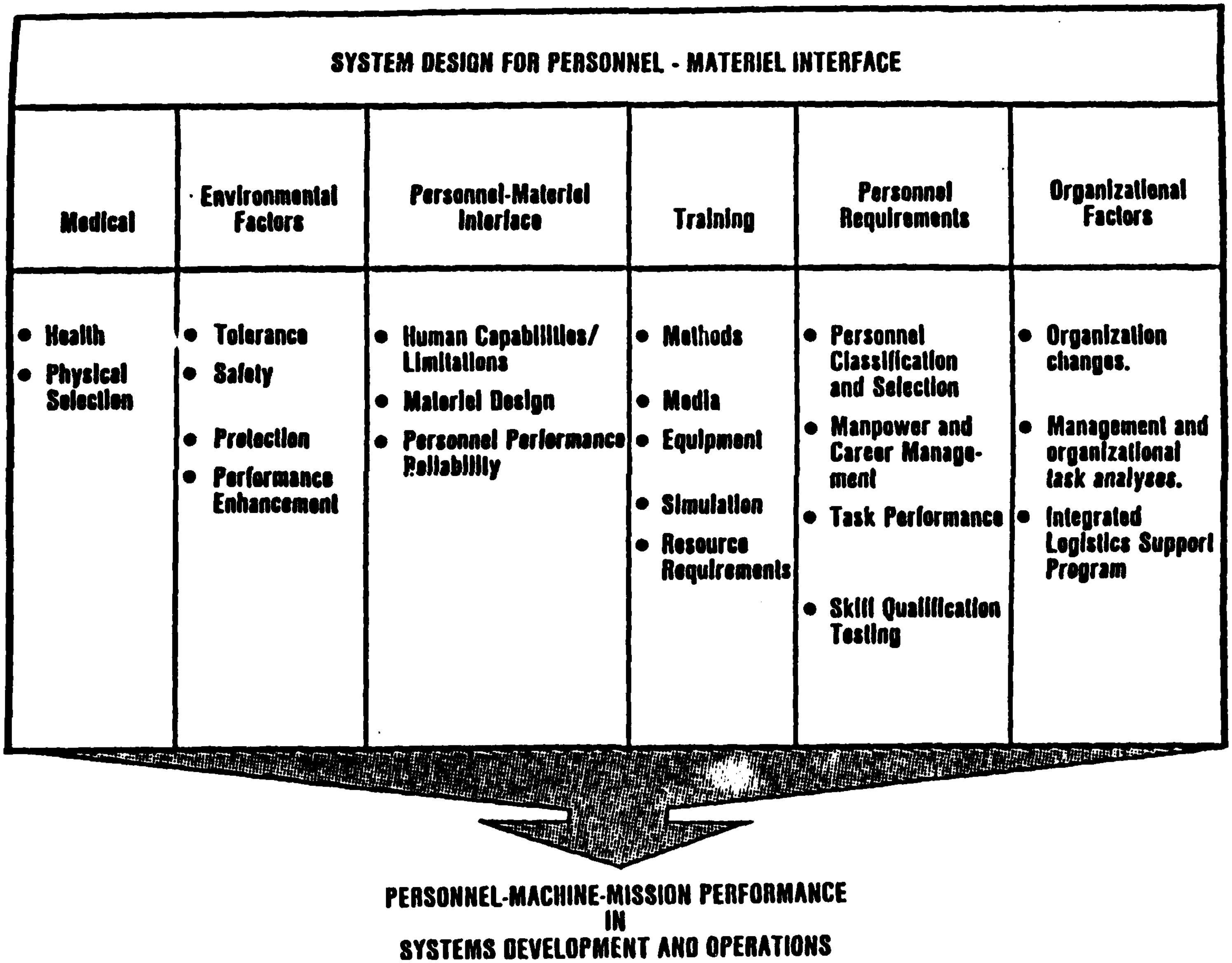

FIGURE 1-2. PERSONNEL CONSIDERATIONS IN SYSTEM EFFECTIVENESS

SECTION II

HUMAN RESOURCES DATA UTILIZATION: CASE STUDIES OF TOS. SOTAS AND XM1

The purpose of this section is to define and discuss the utilization (or lack of utilization) of human resources data in the development of TOS, SOTAS, and XM1. Documentation provided by the government and detailed technical discussions with Department of the Army personnel/defense contractors associated with each system provided the bulk of the data for these case studies. A list of the documentation required under the current system acquisition regulations is contained in Table 2-1. This list was extracted from the regulations reviewed in Appendix B and is presented in the sequence the documents are normally written. Since TOS, SOTAS, and XM1 were both initiated prior to the implementation of current regulations, the documents produced in support of these programs do not track exactly with the required list. However, the correspondence of requirements for documentation between the old and new regulations is similar enough to provide a reasonably close match.

SAI was provided supplemental documentation on these programs, above and beyond that minimally required to support the decision milestones. These additional documents were very relevant to this study effort and provided for a more thorough development of the study objectives. References to these documents are made, where appropriate. throughout the remainder of this section.

Detailed technical discussions were conducted with several Army and civilian agencies. The participants in these discussions were generally very cooperative and provided additional insight to the available documentation. Accordingly, a more thorough understanding of the perspective of each of the programs, in light of the study objectives, was achieved than could have been gained solely through a document review.

The synthesis of the data collection and discussions to date are presented in the paragraphs that follow. TOS is discussed first, followed by SOTAS and XM1.

TABLE 2-1. REQUIRED DOCUMENTATION FOR MAJOR SYSTEM ACQUISITION

Mission Element Need Statement
Special Task Force Report
Letter of Agreement
Task Listing
Decision Coordinating Paper I
Outline Acquisition Plan
DT I Independent Evaluation Plan
DT I Design Plan
DT I Report
DT I Independent Evaluation
OT I Independent Evaluation Plan
OT I Design Plan
OT I Report
OT I Independent Evaluation
Training Support Plan
Logistic Support Plan
Preliminary QQPRI
Tentative Basis of Issue Plan
Cost and Operational Effectiveness Analysis
Cost and Training Effectiveness Analysis
MOS Evaluation
Individual and Collective Training Plan
Training Device Requirements
Required Operational Capability
Acquisition Plan
Initial Recruit and Training Plan
Decision Coordinating Paper II
DT II Independent Evaluation Plan
DT II Design Plan
DT II Report
DT II Independent Evaluation
OT II Independent Evaluation Plan
OT II Design Plan
OT II Report
OT II Independent Evaluation
Final QQPRI
Basis of Issue Plan
MOS Decision
Draft Tables of Organization and Equipment
Updated Training Plan
Updated Acquisition Plan
Decision Coordinating Paper II

2.1 TACTICAL OPERATIONS SYSTEM

The current Army need for a tactical division-level C^3I system is expressed in the TOS ROC[1].

> "Modern Army concepts call for highly effective land combat capabilities for the conduct of tactical operations in any intensity of conflict and geographical environment. To achieve these capabilites, the Army is preparing to introduce important families of sensors, a broad range of second- and third-generation SIGINT [signal intelligence] equipment, and other battlefield systems....Demands for information concerning the capabilities and actions of the highly mobile and lethal opposing forces, coupled with the new and improved communications and battlefield systems, have created a mass of raw data for which an automated tactical operations system (TOS) is required. TOS, a command and control system functioning as the focal point for those new systems, is needed to provide the capability to exchange data with other tactical data systems; data base management; analysis support; and the display capability required by these modern Army system concepts. Specifically, TOS is needed to improve the functions of command and control, and thereby enable the commander and staff to more effectively integrate and employ the battlefield systems which fight, support, and sustain the battle....Emerging intelligence and combat systems will provide the information needed by the commanders and their staffs in such large volumes that traditional manual command and control systems and organizations will be inundated. Utilizing the manual system, the commander and his staff will not be able to respond to the available data fast enough to enable sound and timely decisions to be made and implemented for effective use of his resources."

1 PM TOS, Tactical Operations System Required Operational Capability. Fort Monmouth, NJ: May 19, 1978.

With this need established, the mission of TOS is:

> "...to provide the commander and his staff, in a timely manner, the operations and intelligence information that they require to: see the battlefield; make decisions to exploit enemy force weaknesses, and determine courses of action for the effective employment of friendly resources. As a command and control system, TOS shall have a secondary mission to function as the focal point for the exchange of data with other tactical data systems."[2]

TOS consists of an integrated assembly of hardware, software, and personnel supported by the existing and emerging tactical communications and information distribution system.

2.1.1 TOS System Description

TOS is a computer-assisted tactical information processing system that primarily supports the functional areas of intelligence (G2) and operations (G3). It is an integration of hardware (computer and related peripheral equipment), software (computer programs), computer operating data (files and tables), personnel (system operators, maintainers, and users), and standard communications means. Interface with the computer is accomplished through the use of message input/output devices.

A specific system description of TOS as it is expected to be fielded is difficult to formulate at this time. As will be discussed in the paragraph on the history and current status of the development of TOS, it has evolved through many configurations. These configurations may be summarized as follows:

- From 1958-1964, the system was known as FIELDATA and was directed at the field army level. It was a display-oriented system that provided storage and retrieval of selected information.

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2 PM TOS, System Specification for the Division Tactical Operations System (DTOS), CO-SS-3000-TO. Fort Monmouth, NJ: April 1979.

- From 1964-1970, the system was known as European TOS (EUROTOS), or Seventh Army TOS (SATOS), and was directed at the field army and corps levels. The functional uses of the system were expanded, but basically it remained a storage and retrieval device.

- From 1970-1973, the system was known as Developmental TOS (DEVTOS). The EUROTOS hardware and software were utilized to evaluate automation at the division level during Project Modern Army Selected Systems Test, Evaluation and Review (MASSTER).

- The TOS Operable Segment (TOS^2) (1971-1977) effort was also directed at the division level, and utilized militarized hardware instead of commercial hardware, but remained basically a storage and retrieval device while implementing selected functional areas.

- Division TOS (DTOS) (1973-1979) improved functional areas, developed additional military hardware and addressed alternative configurations down to and including the battalion level.

- The current effort is designated Executive/Control/Subordinate System (ECS^2) and will include field experimentation in Europe.

The system description that follows is that specified in April 1979, which addresses the implementation of TOS from battalion to division level.

TOS shall be a secure, automatic data processing system which serves the command and staff elements of the division at the Tactical Operations Center, Tactical Command Post (TAC CP), subordinate Brigade (BDE) Command Posts (CPs), subordinate Battalion Command Posts, a subordinate Armored Cavalry Squadron, and support liaison points. The system shall provide the capability to aid the commanders in controlling and coordinating tactical operations by providing for receiving, processing, storing, retrieving, and disseminating information concerning the status and location of friendly and enemy units. The TOS shall be secure, be modular, and provide for commonality and interchangeability of hardware components among its functional areas and with other Army tactical systems. In non-tactical deployment, the system shall have the capability to permit

training of user personnel without affecting its mission-ready capability. The TOS functions of collecting, processing, storing, retrieving, and disseminating friendly and enemy unit information shall be carried out in the following functional areas:

- Division Computer Center (DCC). The DCC shall constitute the main data processing and control point and the central data base for the Division TOS. The DCC shall consist of a data base processor, a front-end communications processor, and the large secondary memory to contain the TOS Division data base. The DCC shall be secure, be modular, and provide the capability for data entry, computation, message generation and transmission, message edit and validation, display and print-out of messages, and the ability to control, monitor and configure/reconfigure the digital data and voice nets of the system. The DCC shall also generate and maintain the system data base and disseminate information to users.

- Tactical Computer System (TCS). The TCS shall be a compact, modular, secure data processor and shall provide the capability for data entry, computation, message generation and transmission, message edit and validation, message reception, display and printout of messages in graphic and text format, and monitoring control voice and digital data nets. The TCS, together with its computer programs, is the primary constituent of the Intelligence Element of the Division Tactical Operations Center, Division Tactical Command Post, and the Brigade Command Posts.

- Display/Keyboard and Printer (D/K/P). A TCS Display/Keyboard and Printer, when integrated, will become an Analysis Console.

- Tactical Computer Terminal (TCT). The TCT shall be the primary input/output device of the system. The TCT shall consist of a microprocessor, memory, display, keyboard, two magnetic tape drives, communications modem, and printer for hardcopy output. The TCT shall provide the capability for data entry, message composition, editing and validation, message transmission and reception,

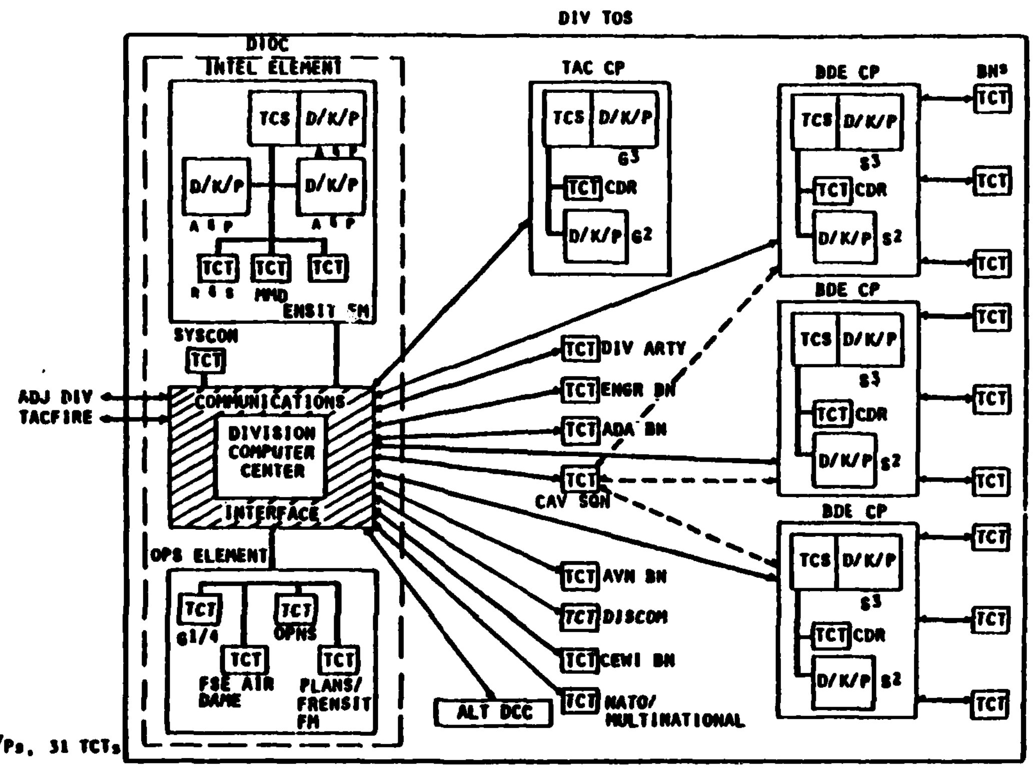
display and printout of messages in graphic and text format, and net monitoring of digital and voice communication. The TCT shall be modular to permit performing functions suitable to its application. To provide maximum flexibility to the commander, the TCT shall be capable of being operated in ground vehicles and command aircraft.

Figure 2-1, reproduced from the aforementioned system specification, depicts the TOS system configuration within the division. The TOS elements identified in the figure are described below:

- Intelligence Element. The Intelligence Element shall have a TCS configured with three D/K/Ps. One of the D/K/Ps shall be used for interactive operator control of the TCS. This operator console and the other two D/K/Ps shall be used for operational interaction for the Analysis and Production Section. The software shall provide for the interaction with three TCTs, one each for the Reconnaissance and Surveillance Section, Mission Management and Dissemination Section, and the Enemy Situation File Manager. The three D/K/Ps shall be capable of performing independent actions simultaneously. For instance, one shall be able to compose text messages while another is receiving a graphic input.

- Operations Element. The Operations Element shall contain four TCTs. One shall be for G1/G4 (plans) and one shall be for G3 (operations). In addition, one shall be used by the Fire Support/G3 Air/Division Airspace Management Element and one shall be used by the G3 Plans/Friendly Situation File Manager.

- TAC CP. The TAC CP shall have a TCS configured with two D/K/Ps. One shall be for the G2 (intelligence) and the other shall be for the G3 (operations). In addition, one of the D/K/Ps shall also function as the computer operator's console. A TCT shall be provided for the division commander. The two D/K/Ps shall be capable of performing independent actions simultaneously such as one composing text messages while the other receives a graphic input.



NOTES:

1. TOTALS PER DIVISION:
   2 DCCs, 5 TCSs, 11 D/K/Ps, 31 TCTs

2. DIVISION TOS (DTOS) IS SUPPORTED BY STANDARD TACTICAL COMMUNICATIONS EQUIPMENT. WITHIN THE DTOC, DTOC COMMUNICATIONS ARE PRIMARILY ACCOMPLISHED BY A COMBINATION OF WIRE AND CABLE. EXTERNAL COMMUNICATIONS ARE PRIMARILY ACCOMPLISHED THROUGH MULTI-CHANNEL OR FM TACTICAL RADIOS

3. LEGEND: ———— PRIMARY LINK.
   -------- ALTERNATE LINK.

FIGURE 2-1. DIVISION TOS CONFIGURATION WITHIN A DIVISION

- BDE CP. The BDE CP shall have a TCS configured with two D/K/Ps. One shall be for S2 and the other shall be for the S3. In addition, one D/K/P shall be used for computer operator control actions. A TCT shall be provided for the BDE commander and up to five remoted TCTs shall be interfaced with the BDE CP for battalion commanders. The capability shall be provided to interface additional TCTs with BDE CP. The two D/K/Ps shall be capable of performing separate actions simultaneously such as one composing text messages while the other receives a graphic input.

- Maneuver Battalion/Other Division Units. DTOS supports the maneuver battalions and other divisional units with a remote input/output TCT on the basis of one per designated unit.

2.1.2 TOS History and Current Status

The first investigation concerning the possible development of automated systems to support tactical command and control operations for the Army was a study program and a series of tests undertaken in 1956 by the Signal Corps. In 1958, the US Army Intelligence Board conducted a study defining user requirements for automated combat intelligence. Simultaneously, five functional subsystems for command and control were identified for automated data processing applications: fire support, intelligence, operations, logistics, and personnel and administration. These efforts provided the initial frame of reference for subsequent TOS development. TOS requirements were refined at Fort Huachuca through 1964.

During this same period, the Army Tactical Operations Center (ARTOC) project provided further insight into storage, retrieval, and display techniques of selected information. The First Intelligence Simulation Test (FIST), conducted at Fort Huachuca in June 1962, confirmed the feasibility of applying automatic storage and retrieval techniques to the processing of tactical intelligence. An ARTOC facility was established at Fort Leavenworth in 1963. Exercise Major Domo in 1964 confirmed the feasibility and desirability of ADP support for the command and control function.[3]

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[3] Using current terminology, this phase of TOS development would correspond to the conceptual or continuing analysis of mission area phase of the system acquisition cycle.

Milestone 0, or the program initiation milestone, was reached in 1964, when the Department of the Army terminated activities at Fort Huachuca and assigned US Army, Europe (USAREUR) the mission to develop, install, operate, and evaluate a developmental TOS and to identify functional areas within a field army where automation could assist commanders in the conduct of operational applications. This concept of applying automation to selected aspects of a military information system was to provide "an incremental approach to the introduction of automation for use in the development of TOS"[4] as reported by USAREUR and Seventh Army. The incremental approach was to be achieved by expanding functional areas and user associated capabilities to the basic software package. Thus, design and implementation, design verification testing, and system evaluation were to proceed concurrently.

Through June 1968 only limited hardware and software capabilities were developed and tested by Seventh Army. The primary functional areas examined during the period were: Friendly Unit Information, Enemy Situation, Nuclear Fire Support, and Effects of the Enemy Nuclear Strikes. These limited capabilities provided for computation, dissemination of information, compilation of summary reports, and preparation of responses to requests for information from within and among the system subscribers at division, corps, and army levels. Because the emphasis of the developmental effort was to be on software concepts and techniques rather than hardware research and development, Seventh Army used "off-the-shelf" commercial equipment and existing tactical communications to create a system known as EUROTOS, or SATOS.

EUROTOS was evaluated during Seventh Army exercises culminating in Command Post Exercise Cardinal System. The results were compared qualitatively with a manual baseline evolved from earlier exercises. Although not all development objectives were achieved, Seventh Army found that EUROTOS significantly improved the thoroughness and speed of information dissemination and that the compilation of information and data in the form of summary reports was significantly faster at army and corps level with the assistance of EUROTOS. The system provided some improvement in the performance of computational tasks. Retrieval of information was significantly faster, more accurate, and generally as complete as in the manual system. When the performance was poor in comparison to the manual system, the fault appeared to be with specific software design

[4] Final Report tactical Operations System (TOS) Development 1964--1969, USAREUR and Seventh Army, December 31, 1969.

problems capable of correction. The overall evaluation[5] favored automated data processing over manual processing of messages.

In January 1970 DA directed the transfer of the system to Fort Hood to continue the refinement of TOS concepts and to participate in Project MASSTER. Based upon the USAREUR and MASSTER findings, the Army decided to direct its efforts towards the development of a computer-assisted command and control system for the division and its subordinate units. Additional MASSTER test results validated the EUROTOS findings, but noted that a high error rate in message text was introduced in comparison with the non-automated system. These high error rates were attributed to man-machine interface problems. MASSTER experiments were constrained by commercial equipment, lack of sufficient input/output devices, and the limitations of functional software. However, the Army assumed that the error rates could be controlled and concluded that selective automation of storage, retrieval, and dissemination functions would provide the commander and his staff with an improved capability.

A study group was formed during July 1971 under the newly chartered Project Manager, Army Tactical Data Systems (ARTADS) to develop a set of procurement specifications for use in the acquisition of TOS hardware and software. Previous studies and tests results were to be used as the baseline set of user requirements.

Guidance for the conduct of the study was provided by the Assistant Vice Chief of Staff, Army (AVCSA)[6] and by PM ARTADS. This guidance for TOS^2 is summarized as follows:

- Use already developed militarized automated data processing equipment as the computer hardware for the TOS^2 as much as possible.

- Determine whether software developed for other Army systems and other Service systems could be applied to TOS^2.

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5 Ibid.

6 PM ARTADS, Tactical Operations System Operable Segment (TOS^2), System Engineering Study Report. Fort Monmouth, NJ: 31 December 1971.

- Direct TOS^2 efforts toward making an early significant step forward in command and control, based initially on austere requirements, and do not be delayed by attempts to perfect technical solutions.

- Field the militarized TOS^2 as soon as practicable for testing by MASSTER, but preserve the option for subsequent proliferation of system components which prove acceptable for a division system.

- Limit TOS^2 to the existing division communications system.

- Use the Draft Basic System Description for Army-wide TOS, as modified by DA, as a basic requirements document. Use the Functional System Design Requirements for Friendly Situation/Enemy Situation, and Army Air Operations as the baseline requirements documents for these specified applications.

- Use computer performance evaluation models to help size and time the system and to help develop the design.

- Employ one central computer center, two remote computer centers, sixteen message input/output devices, and eighteen message input devices. Examine this basic configuration, and recommend changes if required.

The study results[7] were approved by AVCSA in February 1972 and a contract was awarded to Litton Industries in June 1972.[8] Concurrently, DA directed that the TOS^2 software was to be developed by the US Army Computer Systems Command under the sponsorship of the PM ARTADS.

Demonstration and validation testing of the TOS was conducted during March-April 1976 and May-July 1977. The first evaluation was a

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7 The SES Report (ibid.) is comparable to the Special Task Force Report specified in current regulations.

8 This decision was equivalent to Milestone 1 or the approval of for the system to enter the demonstration and validation phase of system acquisition.

command post exercise (FM120) and the second a field command post exercise (FM222), both conducted at Ft. Hood, Texas by the TRADOC Combined Arms Test Activity. Although detailed and well-instrumented tests were planned, TOS was not available for FM120 (due to software errors and faults); and a major portion of its projected capability was inoperative (primarily Standing Request for Information feature) during FM222.

FM222 was a combined DT I/OT I/FDTE designed to develop requirements and recommendations for the Milestone II decision. The independent evaluation of TOS found that "overall, the TOS did not provide a significant benefit to the commanders and staff elements during FM222."[9] They further concluded, however, that "TOS reasonably can be expected to mature into a system which will provide significant assistance in furnishing more timely and complete enemy and friendly situation data to commanders and primary staff...and that the TOS program should proceed into full scale engineering development."[10]

In early 1977 a TRADOC System Manager (TSM) was appointed for TOS as the focal point for TRADOC efforts. He was deeply involved in a major Combined Arms Center (CAC) effort to establish division and corps level software requirements. He was also instrumental in initiating action on a TOS training program.

A special Army Systems Acquisition Review Council (ASARC) in September 1977 rejected early fielding of TOS in fiscal year 1979 in favor of a continued TOS[2] test bed to address problem areas to include additional human factors considerations. A refurbished/enhanced system was to be sent to Ft. Hood for training and evaluation, while two systems were to be sent to Europe. The ASARC II (in January 1978) approved those findings, although the the European fielding was reduced to one system, and directed that the program be continued and proceed to the full scale engineering development phase of the system acquisition process.

Staff members of Office of the Secretary of Defense (OSD) objected to this decision when the program's status was reviewed. Subsequently, the Principal Deputy Under Secretary of Defense (Research and Engineering) in October 1978 directed the Army to complete several actions; the foremost was "to demonstrate, with test results, the military use of automation to assist division tactical

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9 OTEA, Independent Evaluation of the Tactical Operation System. Falls Church, VA: January 1978.

10 Ibid., p. vii.

command and control operations."[11] The Army was responsive to these concerns in their revisions, which provided for development and test of three alternative configurations of Division TOS, leading to a Defense Systems Acquisition Review Council (DSARC) II consideration in 1982. Subsequent OSD guidance stated that the military utility of the system was to be demonstrated at alternative levels of automation, and that the Army should be ready for a production decision at DSARC II.

Specific information concerning the alternative levels of automation and explicit configurations of TOS that will be evaluated during future tests were not available to the study team. However, during discussions held with the Office of the Project Manager (OPM) TOS it was learned that within a command echelon the configuration will basically remain the same. Future tests will examine to what level below division automation should be applied to assist the commander and his staff in their command and control functions.

2.1.3 Utilization of Human Resource Data During TOS Development

2.1.3.1 BESRL Support to EUROTOS

During the EUROTOS period the predecessor to ARI, the US Army Behavioral Science Research Laboratory (BESRL), provided support to the TOS program with both field and laboratory approaches. The field approach was implemented through the BESRL Field Branch in residence at the Seventh Army TOS in Heidelberg, Germany. A number of conclusions derived from these studies are discussed below.

Research was conducted to compare the use of electro-mechanical devices to electronic devices for TOS input and output. Teletypewriters were compared to cathode ray tubes (CRTs) with typewriter keyboards. BESRL concluded that TOS' use of CRTs was, in fact, the superior mode.[12]

The transform operation is the process of translating free text into a standard system format. A considerable amount of effort was expended on analyzing the TOS transform operation. Experiments

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11 US General Accounting Office, Tactical Operations System Development Should Not Continue as Planned. Washington, D.C.: November 20, 1979.

12 Seymour Ringel, James D. Baker, Michael Strub, and Loren K. Kensinger, Human Factors Research in Command Information Processing Systems--Summary of Recent Studies, TDR 1158. BESRL, Arlington, VA: July 1969, p. 3.

were conducted to examine the interface between the action officer (AO) and the User Input/Output Data (UIOD) operator and to reduce formatting efforts during input.

EUROTOS called for both an AO and a UIOD operator. The AO selected a message format and filled it out, then gave it to the UIOD, who entered onto the CRT. BESRL's recommendation was to merge the two positions and have the AO also enter the data directly into the system.

An analysis of the input process showed an error rate of 22% in the selection of message format. A job-aid was developed to assist in format selection. Tests showed that no improvement in the error rate resulted. It was concluded that the process itself needed to be changed, rather than merely aided.[13]

Research was conducted comparing graphic vs alpha-numeric methods of data presentation. This was motivated by the fact that, while much information is traditionally displayed in graphic forms (e.g., map symbols), TOS stored all information alpha-numerically. It was determined that there was no degradation due to use of all alpha-numeric displays. BESRL recommended that all alpha-numeric displays be used. (Since then, of course, the state-of-the-art of mini-computers has advanced so that TOS can incorporate graphics displays.)

Procedures then employed by Seventh Army called for the G2 to apply a 6-point accuracy rating and 6-point reliability rating to each spot report. Experiments with job aids improved neither speed nor accuracy. BESRL recommended simplifying the rating method, perhaps by the use of subjective probabilities.[15]

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[13] J.D. Baker, D.J. Mace, and J.M. McKendry, The Transform Operation in TOS: An Assessment of the Human Component, TRN 212. BESRL, Arlington, VA: July 1969.

[14] F. L. Vicino and S. Ringel, Decision Making with Updated Graphics vs. Alpha-Numeric Information, TRN 178. BESRL, Arlington, VA: November 1966.

[15] Ringel, Baker, et. al., op. cit, pp. 4-5.

BESRL also noted:

> "One of the very real problems...deals with the impact of automation on Seventh Army users. In the research-development-production-distribution gamut, those in the research environment may lose sight of the fact that users of the new system may not be as intimately acquainted with them as are the research scientists who design them. User reaction to a new product must be favorable--a successful research program may be nullified by a user's refusal to accept innovations."[16]

Research was also conducted on the potential use of tactical decision aids. BESRL concluded that computer aids to tactical decision making may yield substantial payoffs in combat situations about which the data are typically conflicting and of low reliability.

2.1.3.2 System Engineering Study

The next major milestone of TOS was the System Engineering Study (SES) Report of 1971.[17] The team organized under this ambitious effort was given detailed guidance which included the use of developed or "off-the-shelf" militarized computer hardware and the continuation of TOS as a storage and retrieval device. The emphasis was on early fielding of the system based "initially on austere requirements and not be delayed by attempts to perfect technical solutions."[18] It is obvious that time and funds were of the essence and prevented the TOS team from examining all aspects of the system design.

The TOS team (without the benefit of any assigned applied psychologists) produced a voluminous report specifying the adoption of existing hardware and the development of software for the TOS[2] test bed. The selected configuration (hardware, software, and user/operator personnel) was dictated by the force structure which the

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16 Ibid., pp. 7-8.

17 SES Report, op. cit.

18 Ibid., p. 4.

system is designed to support and the general hardware configuration as developed in previous test reports and studies. The actual number of user devices for TOS were provided as guidance to the study team,[19] so there was very little opportunity to examine alternative configurations.

Accordingly, the SES report was directed at the technical aspects of selecting off-the-shelf military hardware which would satisfy the requirements for a TOS^2 test bed and fully define the functional areas to be implemented in the software during the test bed phase of the development. An analysis of the report yields no information that would indicate that human resources or human factors were given any consideration. Even the TOS acquisition management plan, which was one of the products of the study, only addressed human factors from a quality assurance perspective in that "...provisions should ensure simplicity and understandability of software implementation, operations, training and reference material with respect to man/system interface; and the application of human factor skills and techniques in system and software design phases such as coding schemes and message lengths."[20] No guidance or direction was forthcoming from the study or the management plan which indicated that human resources would or should be given proper consideration in the system.

2.1.3.3 HEL Support

Based upon the SES report, the development of TOS^2 test bed was undertaken. From a review of the available documentation and technical discussions with personnel associated with the program, it is apparent that personnel familiar with human factors applications to system design were not involved in the program until late 1975. During FM120 and FM222 the US Army Human Engineering Laboratory (HEL) evaluated "the TOS^2 test bed software and systems integration...hardware was not evaluated except in isolated cases because it was evaluated on the TACFIRE system."[21] The primary objective of HEL's evaluation was to "observe system use and prepare recommendations that

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19 Ibid., p. 16.

20 Ibid., p. IV-10.

21 A.H. Keiser, Tactical Operating System Operable Segment Test-Bed Human Factors Evaluation. US Army Human Engineering Laboratory, Aberdeen, MD: July 1977, p. 1.

would simplify the man-machine interfaces and reduce user training and skill requirements."[22] This implies that the objective was to evaluate the "how" of the interface and not answer the more fundamental questions of "who," "where," and "why" of the system design. The HEL tasking was too narrow in scope and lacked sufficient resources to answer those latter questions.

Nevertheless, HEL was able to offer many recommendations, based upon FM120, that would simplify the man-machine interface considerably. Many human factors problem areas were identified and many solutions were provided. Most of the HEL report centered around the Message Input/Output Device (MIOD) and the computer center operator/system controller. HEL's recommendations concerned the implementation of an interactive dialogue with a cueing/prompting feature to the operator in order to reduce the number of keying actions required of the operator to store and retrieve information from the MIOD or to initialize and maintain the system. These "devices" require the operator to be a relatively proficient typist and to learn a large number of rules and codes to use and enter data into the software display formats. These skills are not normally associated with the MOSs of those personnel who would be expected to fill these positions within the manual system. It was apparent from the HEL report that the lack of human factor and personnel considerations in the design stage of TOS had produced a system that was very unsatisfactory from the operator's point of view.

HEL also participated in the evaluation of TOS during FM222. It is significant to note that virtually the same human factors problems uncovered in FM120 were again highlighted during this test. This was to be expected, since only a year had elapsed between the two tests. This time period would be insufficient to correct all the deficiencies. The independent evaluation report on FM222 concluded that although computers can be used in the field by troops:

- The MIODs are unacceptable as input/output devices for TOS. The work environment in the vicinity of the MIODs was unsatisfactory and the devices had limited capabilities.

- The TOS test bed formats and the data element dictionary are too complex and rigid.

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22 Ibid., p. 2.

- Information availability and timeliness were constrained by the backlogs and workloads at the receiving staff sections. TOS probably will not significantly improve availability or timeliness, unless it assists the staff in rapidly processing information (for example, by updating files, notifying other elements, discarding information, sorting, categorizing, and changing displays).

- There is a substantial opportunity for a trade-off of TOS software development efforts versus human factor acceptability and training burden.[23]

All of the above conclusions provide ample evidence that human factors and human resources were not adequately considered during the design and development of TOS. Consequently, when human operators were required to operate the equipment in a test environment, they were overwhelmed by the man-computer interface problem. This factor, along with significant hardware and software design technical problems, ultimately undermined the primary objectives of the tests, i.e., to evaluate the operational effectiveness and military utility of the TOS as a computer-assisted command and control system.

2.1.3.4 ARI Research on Data Entry

During the DEVTOS period ARI conducted a number of research projects on the data entry process. This paragraph provides some brief references.

An analysis of on-line (using the terminal) vs off-line (using paper formats) preparation of TOS messages with and without verification was conducted in a laboratory environment. It was found that on-line verification resulted in significantly fewer errors with

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[23] OTEA, op. cit., p. 79.

no reliable difference in input speed. Verification resulted in reduced errors, but at a time and manpower penalty.[24]

The use of feedback in TOS training systems was the subject of another experiment. It was found that feedback could reduce training time for data entry, but did not improve accuracy. The appropriateness of incorporating feedback into TOS training depended upon the cost of training time.[25]

Several types of typing aids were examined to assist message entry to TOS. While no increase in speed could be found, menu selection was found to reduce the number of errors.[26]

Two types of reference codes were used in early versions of TOS: one consisting of two letters and number (LL#) and one consisting of four letters (LLLL), usually an acronym. It was found that the latter method could be learned in 60 percent of the time of the former and resulted in less than half the error rate.[27]

The Alpha-dot system is a non-standard keyboard where the keys to be pressed are determined by the shape of the alpha-numeric character being entered. With less than five hours practice, trainee's using the Alpha-dot tablet were able to enter free messages at 60 percent of their standard keyboard rate.[28]

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24 M.H. Strub, Evaluation of Man-Computer Input Technique for Military Information Systems, TRN 226. ARI, Arlington, VA: May 1971.

25 P.A. Gade, A.F. Fields, and I.N. Alderman, Selective Feedback as a Training Aid to On-Line Tactical Data Inputting, TP 349. ARI, Alexandria, VA: November 1978.

26 A. F. Fields, R. E. Maisano, and C.F. Marshall, A Comparative Analysis of Methods for Tactical Inputting, TP 327. ARI, Alexandria, VA: September 1978.

27 C.O. Nystrom and G.M. Gividen, East of Learning Alternative TOS Message Reference Codes, TP 326. ARI, Alexandria, VA: September 1978.

28 R.C. Sidorsky, Alpha-Dot: A New Approach to Direct Computer Entry of Battlefield Data, TP 249. ARI, Arlington, VA: January 1974.

2.1.3.5 SIMTOS

From 1967 to 1977 ARI conducted an extensive laboratory analysis of tactical information processing under the rubric *Simulated* Tactical Operations System (SIMTOS). In spite of its name, SIMTOS was not a simulation of TOS, nor was it ever intended to be, although it did employ some equipment similar to SATOS. SIMTOS was designed for the purpose of studying human performance (i.e., decision making) in an automated tactical military information setting. An extensive description of SIMTOS and its research program is not possible here, but a brief discussion is appropriate.

SIMTOS was a physical simulation consisting of hardware and software where players (G2s or G3s) were presented with tasking in the context of a scenario and data base. The system simulated both the player's superiors (who contact him through staff memoranda or battle orders) and the player's staff (with whom he communicates via CRT or teletypewriter). Through the agency of the computer the player sees the battle action unfold before him and he takes appropriate steps to execute his mission.[29]

The earliest formal SIMTOS research was a series of experiments intended to evaluate player performance measures and identify other variables which correlated with them. A scoring standard based upon the expert opinion of Army Command and General Staff College (CGSC) instructors was used in the subsequent analysis. Two aspects of CGSC (recency of attendance and class standing) showed strong correlation to the performance criterion. Analysis concluded, however, that the variables analyzed did not predict player performance consistently.[30]

Two experiments were conducted on display effectiveness. One compared tote (alpha-numeric) to graphic displays;[31] the second

29 J.D. Baker, "SIMTOS: A Man-In-The-Loop Interactive Simulation of a Tactical Operations System" in Military Strategy and Tactics (Eds: R.K. Huber, L.F. Jones, and E. Reine). Plenum, New York: 1975.

30 J.E. Robins, L. Buffardi, T.G. Ryan, Research on Tactical Decision Making, TP 246. ARI, Arlington, VA: March 1974.

31 L.H. Nawrocki, Graphic versus Tote Display of Information in a Simulated Tactical Operations System, TRN 243. ARI, Arlington, VA: June 1973.

compared standard to reduced-detail maps.[32] Neither experiment showed significant differences.

A series of two experiments were conducted to explore the use of decision aids. Two situation aids and one resource allocation aid were developed and tested. In neither experiment did the player's performance differ significantly between aided and unaided players.

It should be emphasized that while the SIMTOS work was to some extent inspired by TOS, SIMTOS was conducted in parallel to and not part of TOS. OPM TOS does not appear to have utilized the SIMTOS results, nor to have appreciated their significance to the TOS effort.

2.1.3.6 Summary Discussion

Most TOS subject matter experts interviewed by the SAI study team seem to believe that TOS can provide an enhanced command and control capability of tactical forces at the division level if only certain aspects are corrected. Many of these corrections involve the proper use of human resource considerations. For instance, a complete statement of functional requirements is necessary to identify and substantiate the needs of the primary user--the battlefield commander. These requirements have never been developed. Functional requirements would have provided the basis for defining what the system is required to do in command and control of tactical operations. Instead, it has been arbitrarily assumed from the beginning that TOS would be relegated to a storage and retrieval device for tactical information. This assumption effectively precluded an examination or consideration of what the commander really does, i.e., make decisions.

All staff procedures may be categorized into one of the following three functions:

- Input staff processing
- Decision making
- Output information processing.

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[32] T.M. Granda, A Comparison between a Standard Map and a Reduced Detail Map within a Simulated Tactical Operations System (SIMTOS), TP 274. ARI, Arlington, VA: June 1976.

Formal Army instruction at CGSC in command and staff operations and procedures concentrates on the decision making functions. As a result, the student is hardly aware of the decision maker's dependence on the two information processing functions. The opportunity for delays and errors in information processing is far greater than in decision making, and their impact on combat outcome is more fundamental. It is believed that the developers of TOS recognized this fundamental precept and designed TOS as a system solely designed to collate increasing amounts of information, faster, and with minimum errors. There was little consideration as to how this information was to be linked to the decision maker. Automated functions must improve and support the decision making of the commander and his staff, not merely provide him automated information.

It may be conjectured that thorough functional requirements analysis to determine how both man and machine should be utilized within the system may have precluded much of the controversy that surrounds TOS today. For example, commanders and their staffs who have used the system in the FM120 and FM122 test environment, have said that:[33]

- "TOS will not help me as a commander."
- "Cost of the input is not worth the information out."
- "TOS information is not in an acceptable form to me."
- "I am a servant to the software."
- "Computers should assist, not impose."

All of these comments further indicate that the system was not designed to support the commander's decision-making functions nor, as some have said, even with the operator or ultimate user (namely, the commander) in mind.

It has been argued that not only are the decisions the prerogative of the commander, but also the manner in which he makes these decisions. If this assertion is accepted as valid, then it follows that TOS should be no more than a storage and retrieval device of tactical information arrayed within well defined functional categories in a manner of use to the commander and his staff. In

[33] These quotes from commanders and staff involved in the evaluation of TOS were provided to the SAI study team by US Army Materiel Systems Analysis Agency (AMSAA) personnel who observed FM222.

other words, there is no requirement to provide decision-aiding algorithms like those previously mentioned. All of the evidence indicates that this is the assumption under which TOS has been specified within the SES and subsequently developed as the TOS[2] test bed for evaluation during FM120 and FM122.

A majority of the problems presented in the OTEA's independent evaluation of FM222[34] and the HEL's human factor evaluation[35] might have been avoided if studies had been undertaken to determine crew size and required skills, optimal work station layouts, individual and crew training requirements, operator-machine interactive dialogue techniques, and methods for commander and staff interaction with the operator. As previously mentioned, comments from the two reports indicate that lack of attention to these basic human resource considerations led to major problems for those charged with approving the continued development of the system. These problems led Mr. Hunter Woodall, Assistant Deputy Under Secretary of the Army (Operations Research) to state at ASARC II "...the human factors problems were not insignificant...[they] wouldn't let the system go forward."[36]

Since that time, HEL has been working very closely with OPM TOS and the TOS software support center to correct the human factors deficiencies noted in FM120 and FM222. Personnel from HEL indicated they have had excellent success in improving prompting aids, reducing the number of key actions required of the operator, and lessening operator dependence on the data element dictionary. As a result of these successes, required operator typing skills have been reduced. HEL has also been able to provide guidance to improve the software formats and reduce the errors associated with inputting of data into the formats. HEL provided trained human factor personnel to observe how the man functions within the system, his strengths and his limitations. Application of this knowledge to the design of the software resulted in improved man-machine interface. Ideally, this human factors expertise should have been included in the SES effort or at least provided at the onset of the TOS[2] test-bed development. A concentrated effort is currently being made by OPM TOS and Singer Company, who is developing much of the hardware for the upcoming

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34 OTEA, op. cit.

35 Kaiser, op. cit.

36 This quote was attributed to Mr. Woodall by AMSAA staff members who were present at ASARC II.

Europe evaluations, to correct other human factor problems as noted above. The study team was not able to ascertain the extent or the degree of success of this effort.

When one looks at the whole TOS program in retrospect, it is very easy to see where decisions could have been made to consider man's role in the system. There are, however, several factors that constrained the OPM from having greater sensitivity to human factors.

First, after the issuance of the SES report, TOS effectively extended the demonstration and validation phase of the system acquisition cycle. Because of funding and schedule constraints, TACFIRE equipment was selected as the baseline hardware. TACFIRE formats and information processing methods were chosen as guides for future TOS software development. The TOS team assumed that TACFIRE hardware and software satisfied all human factors criteria.

Second, the system configuration was dictated by DA, thus there was little chance to experiment with different manning levels, etc.

Third, there were no human factors personnel or applied psychologists familiar with automated data processing systems on the TOS design team. Personnel with these qualifications are trained to recognize potential problems and can often recommend solutions or trade-offs before the problems occur or before the cost of changing the system or subsystem becomes prohibitive. During TOS development this type of personnel was not utilized until it came time to evaluate the system. They were not utilized during the design of the system nor to assist in selecting off-the-shelf hardware.

Fourth, training for the tests was inadequate. System evaluations prior to FM120 and FM222, for example EUROTOS, did demonstrate that field troops could be trained to use the system effectively. However, during FM222, the unit assigned to TOS was trained to operate the system during off-duty hours. This obviously is not conducive to establishing a good training environment, but PM TOS had no control over the situation.

The last major factor which prevented inclusion of human resource considerations into the system was a perceived need for the immediate development of an automated command and control system. Almost since the beginning of the development of TOS there has been a sense of urgency to field the system as rapidly as possible--automation for automation's sake if nothing else. In hindsight, with no definitive functional requirements and with the normal personnel turnover experienced throughout all the agencies involved in the development of TOS, this may have been an impossible task.

2.2 STAND-OFF TARGET ACQUISITION SYSTEM

The current Army need for a target acquisition and surveillance system is contained in the SOTAS ROC.[37] Although the specific need is classified, it may be summarized from the open literature as follows:

> "During the conduct of tactical operations against a major well organized, highly mobile, modern force, the division Commander requires timely and accurate information about the battlefield itself and those enemy activities which may affect the accomplishment of his mission. The Commander requires this information to more effectively concentrate his combat power at critical times and places and employ his supporting arms. Demands for this information requires a system for detecting and locating enemy targets beyond the line of sight from ground positions. The system should operate behind the FEBA [Forward Edge of the Battle Area] in a relatively secure position and look out beyond the FEBA to detect the movement of reserve elements of the opposing force, together with the build-up of second echelon units, in order that they can be engaged by artillery and air support. It is necessary that this detection and location capability provide surveillance over a wide area, and that it operate day and night in virtually any weather."[38]

With this need established, the mission of SOTAS can be stated as:

> "to provide the Commander and his staff the capability to monitor enemy activity on the battlefield, a target acquisition capability for engagement of targets at long ranges, and a system to

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37 PM SOTAS, Stand-off Target Acquisition System Required Operational Capability (U). Fort Monmouth, NJ: May 3, 1978. (CONFIDENTIAL)

38 Dan Boyle, "SOTAS--Single Most Effective and Valuable Collector of Intelligence," INTERAVIA. Geneva, Switzerland: Vol XXXV, March 1980.

collect and disseminate this tactical information on a near-real time basis."[39]

From the above, it is obvious then that SOTAS, like TOS, is also an emerging C^3I system that is being developed to satisfy the demand for improved command, control, and intelligence collecting activities of the division commander. At this point, it is significant to note two primary differences between the systems. TOS is an automated C^3I system being developed to partially replace an existing manual system which is central to the conduct of tactical operations for the division commander. SOTAS is an automated C^3I system being developed to fill a void in the existing intelligence collecting capability of the division which will be employed in support of the division commander during the conduct of tactical operations. This distinction between the two systems and its relevance to the current effort will be discussed below.

2.2.1 SOTAS System Description

SOTAS is a C^3I system designed to collect, display, and disseminate target and intelligence data to tactical unit commanders in a combat environment. Accordingly, it will provide commanders the capability to monitor the enemy forces on the battlefield in real time and acquire moving targets beyond the FEBA in order to more effectively deploy forces, direct fire power, and vector aircraft to targets.

SOTAS' development has been evolutionary in nature. Hence, the system description is itself something of a moving target. The description presented here is that of the so-called Interim-Interim (I^2) SOTAS currently deployed to Europe. SOTAS consists of three major subsystems: a radar mounted on an airborne platform, a positioning subsystem, and a ground display subsystem. A brief description of each subsystem follows:

- The airborne subsystem consists of a UH-1H helicopter equipped with a moving target indicator (MTI) radar. (It is intended that the production SOTAS will use a BLACKHAWK helicopter.) The airborne platform is positioned via voice vectors so that the radar can detect movement on or near the ground in designated areas or sectors. Radar returns and platform

[39] Ibid.

positional data are transmitted to the ground display station via air-to-ground data links.

- The positioning subsystem is a portable device used to provide signals to the airborne platform in order for it to pinpoint its location relative to a known reference point. It also provides a reference point to permit the calibration of the antenna pointing angle as calculated by the heading reference subsystem.

- The ground display station consists of a twenty-foot processing and display van pulled by a five-ton truck with a sixty KW generator. The station processes, displays, and disseminates data received from the airborne platform. Data displays use synthetic data to develop information concerning military movement and potential targets. This information is communicated to the Division users, e.g., Division Artillery (DIV ARTY) and BDE CPs. The van houses the SOTAS operators and is the nerve center of the SOTAS system.

The current SOTAS employment concept provides for a single ground station deployed at the division main command post. Future plans call for evaluating secondary ground stations at each brigade headquarters in addition to the primary ground station.

The SOTAS ground display station requires a crew of four to operate: a Target Surveillance Supervisor (TSS) (who also serves as the officer-in-charge), two Search and Track Operators (STOs), and a Radio-Telephone Operator (RTO). The following description was derived from the systems operating procedures.[40]

The TSS's work station consists of a standard data terminal with alpha-numeric keyboard, status display and a map digitizer.

- The data terminal provides hardcopy records while the keyboard is used by the TSS to interact with the system.

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[40] D. M. Larson, B. C. Linge, L. M. Heeringa, K. B. Collyard, F. C. Foss, I² SOTAS Ground Station Operating Procedures (U). Honeywell Corporation: August 1978. (CONFIDENTIAL)

- The status display provides information concerning the status of targets held in the target file, system operating parameters, and system malfunctions.

- The map digitizer is a back-lighted map table with a map bug which allows correlations to be established between military maps and radar data.

- The TSS monitors all tactical communication nets.

Each STO performs his functions at a display console. These display consoles are the primary interface between the SOTAS crews and the radar and computer subsystems. The displays show graphics, processed MTI radar imagery, the target file data, the target file index, advisory messages to the operator, real-time cursor coordinates, time compression parameters, and alpha-numeric entries from the keyboard. The keyboard allows for the entry of Universal Transverse Mercator (UTM) coordinates, free text messages, and can be used for graphics. Each STO also has a functional keyboard used to control the imagery on the display or to direct the system to perform specific actions.

The RTO monitors all radios and communication nets required with the system.

Figure 2-2, provided by Honeywell, depicts the layout for the SOTAS primary ground station. Figure 2-3, also provided by Honeywell, is a graphic representation of the information flow within the SOTAS system. In addition to providing additional insight to the SOTAS system description, these figures are key to the incorporation of human resources data into the system development. As such they will be addressed again.

2.2.2 SOTAS History and Current Status

OPM SOTAS placed restrictions on the documents available to the study teams. Only documents directly related to human factors were reviewed and, with one exception (OTEA), technical discussions were held only with persons in OPM SOTAS or with support contractors to PM SOTAS. Even the available test results were developed and analyzed by PM SOTAS or its support contractors.[41] All of the evidence presented

[41] Even DT/OT I was conducted by PM SOTAS, somewhat unusual for a major system.

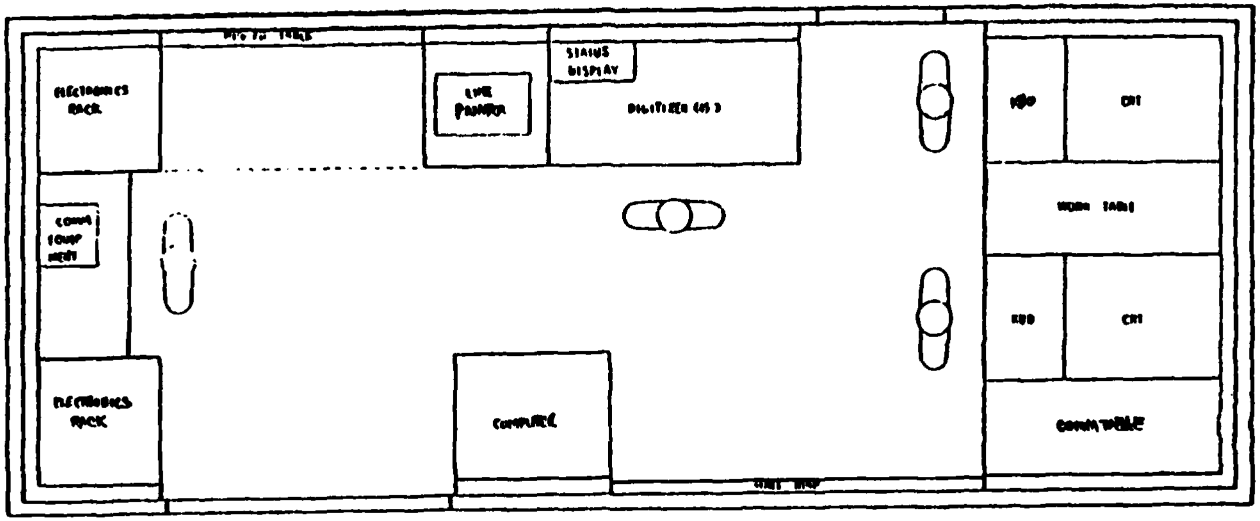

FIGURE 2-2. SOTAS PRIMARY GROUND STATION VAN LAYOUT

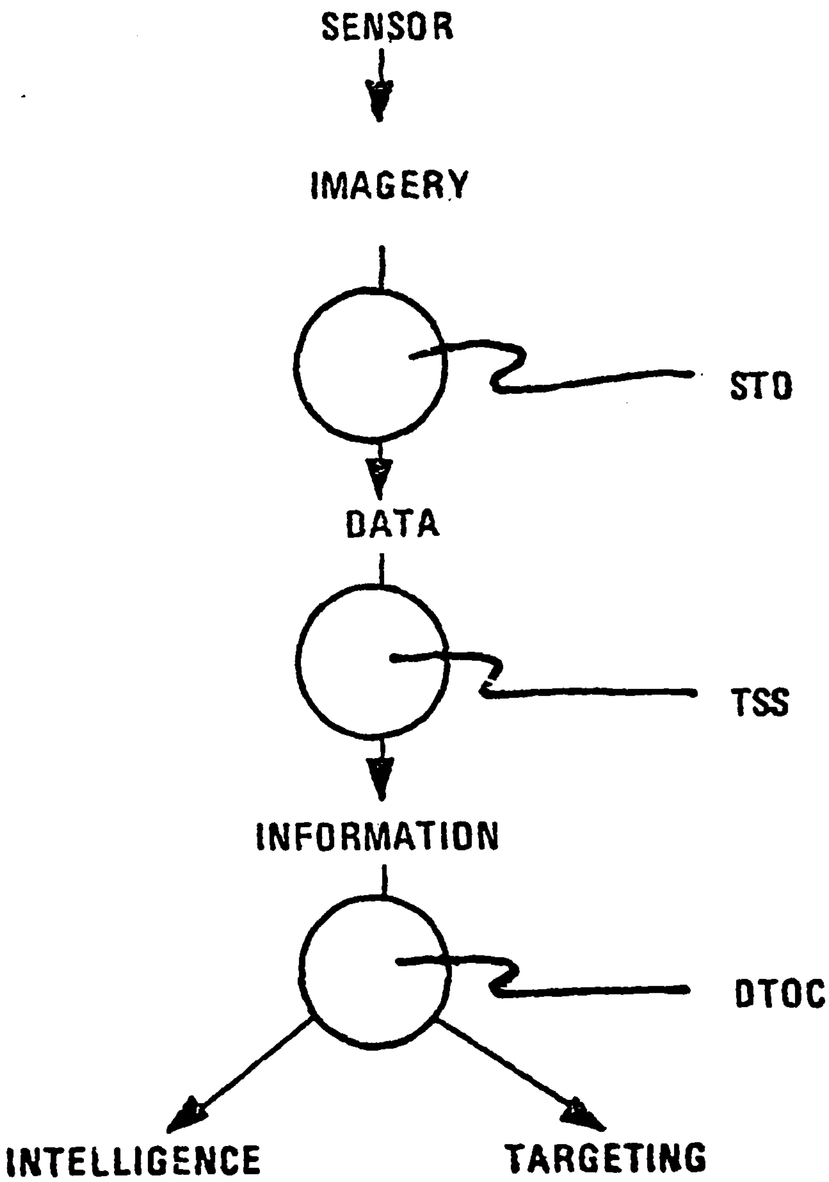

FIGURE 2-3. SOTAS INFORMATION TRANSFER MODEL

to the study team showed the "success-oriented" attitude expected of a project management office. However, even with this caveat in mind, the study team is convinced that SOTAS is a remarkably successful program and an excellent example of how human factors/human resources should be developed and integrated in a military system.

The SOTAS evolved from the Alerting Long Range Airborne Radar for Moving Targets (ALARM) feasibility and concept tests and studies conducted from 1970-1975. During this concept formulation period it was demonstrated that:

- A standard Army helicopter could fly with a rotating antenna.
- Radar data could be transmitted to a ground station.
- Time compression and graphics were feasible in the display element.

Based upon these feasibility efforts, the Director, Defense Research and Engineering (DDR&E)[42] directed DA in 1974 to pursue the development of SOTAS. Effectively, the system moved into the demonstration and validation phase of the system acquisition cycle. The concept for the continued development of SOTAS was to provide for command and control for airborne battlefield surveillance and target acquisition of moving targets.

In late 1974 PM SOTAS was chartered to manage the development of the system. PM SOTAS immediately assembled a team of contractors to support program development. General Dynamics was chosen as the prime hardware contractor. Honeywell Corporation provided human factors expertise, Systems Planning Corporation (SPC) provided system analysis capabilities, and Technology Research Corporation provided advanced radar research; these three support contractors were not subcontractors to the prime, but were directly responsible to the PM. This single manager technique successfully integrated all facets of the system's development by providing each facet an equal "voice" concerning trade-offs in the system design. With the exception of the hardware contractor this team is still with the program.

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[42] Now the Under Secretary of Defense (Research and Engineering) (USD(RE)).

During April-June 1975 the Combat Developments Experimentation Command (CDEC) and the Electronics Command (ECOM) conducted SOTAS demonstrations at Hunter-Liggett Military Reservation in California. These demonstrations indicated that the SOTAS crew were able to detect and track moving targets and vector attack helicopters, that trilateration does not improve accuracy, and that the closed-loop targeting capability was feasible.

This was followed later in 1975 by personnel experiments conducted by Honeywell Corporation at the General Dynamics San Diego facilities to provide data on the personnel skills required to operate the sytem.

Still later in 1975 the Army and the Air Force conducted tests at White Sands Missile Range. These tests comfirmed the feasibility of SOTAS to provide useful target acquisition data.

In May 1976 SOTAS had its first field trial. The SOTAS team went to Korea for a demonstration of its ability to operate with the 2nd Infantry Division's All-Source Intelligence Center (ASIC). SOTAS again demonstrated its potential. The OPM's team gained valuable insight into operational problems. However, one of the most important results of the Korea test was that the SOTAS concept was favorably received by the user (after initial skepticism).[43] The frequent, positive interaction between PM SOTAS and the user initiated during this test and carried on in subsequent field trials was, in the study team's opinion, critical to the development and acceptance of the SOTAS system.

During 1976, 1977, 1978, 1979 SOTAS participated in the annual REFORGER exercises in Europe.[44] During each of these exercises the PM SOTAS was able to validate on-going modifications and to expand his testing objectives from narrow feasibility demonstrations of the concept to successful integration with the participating divisions' tactical operations centers. After each exercise, modifications were made to the system design to improve its potential use during the next exercise.

43 As related by DPM SOTAS during technical discussions.

44 The REFORGER 76 test satisfied the requirements for DT/OT I.

This concept of modify the system, test and validate the modifications, apply additional modifications, and then retest proved so successful in converging on the final design that the ASARC/DSARC II decision milestone was moved up to March-August 1978. At that time the decision was made to enter the full-scale engineering development phase of the system acquisition cycle. A competitive Request for Proposals (RFP) was let for the system hardware. The prime contract was awarded to Motorola in 1979. PM SOTAS retained the support contractors on the program, although their tasking was modified to reflect current system design and development objectives.

Also in 1979 an I^2 SOTAS was experimentally fielded in Europe with the objective of refining training objectives and clarifying integration of the system into the intelligence gathering units of an Army division.

Currently the system is scheduled to undergo DT II/OT II early in 1982 with ASARC/DSARC III, the production decision, following in the fall of 1982.

2.2.3 Utilization of Human Resources Data During SOTAS Development

The effective employment of human resources data in the system design has been continuous in the SOTAS program almost since the initial milestone review. PM SOTAS recognized that several complex human engineering problems had to be solved before SOTAS could become an operationally effective system. He also recognized that human factors considerations were being placed in a secondary role to hardware technology when system design trade-offs were being conducted. Based upon his recommendations, OPM SOTAS contracted for human factor support from Honeywell Corporation and shifted the responsibility for human factors considerations from General Dynamics to the PM's office. As previously mentioned, OPM SOTAS also assumed direct responsibility for systems analysis and radar research via support contractors. This single manager concept provided independent channels for system design recommendations to the office with charter responsibility for the system. This management concept has a negative aspect in that it increases the span of control for the OPM, but that does not appear to have been detrimental in the case of SOTAS.

Now that it has been established that human resources have been considered in SOTAS development the question remains: "What was done and when was it done?" Honeywell's tasking encompassed the following objectives:

- Determine operator functions and information requirements related to the total SOTAS command and control environment.

- Provide data and facilities which address specific system design questions and issues regarding the operator's role in system operation.

- Recommend procedures, manning levels, aiding techniques, training requirements, evaluation criteria, and HFE Guidelines throughout the course of SOTAS engineering development.

With these broad objectives, Honeywell established an initial program to resolve major issues and then continually narrowed their focus to refine and validate resolutions.

Figure 2-4 is a block diagram which is representative of this process. As can be seen, it provides for continual refinement of any implemented solution and the identification of new problem areas. Honeywell has used this mechanism to provide critical input to:

- Allocation of functions between individuals and machines to include aiding techniques

- Number of operating crew and their structure

- Allocation of functions among crew members

- Training systems analysis for both individuals and crew

- Information flow within and external to the system

- Work station design to include alpha-numeric/ functional keyboard layout, information formats and work space arrangement

- Van layout to include operator and equipment positions.

Honeywell personnel were able to achieve this impact on SOTAS due to the constant exposure afforded the system to user personnel and the development of a SOTAS simulator.

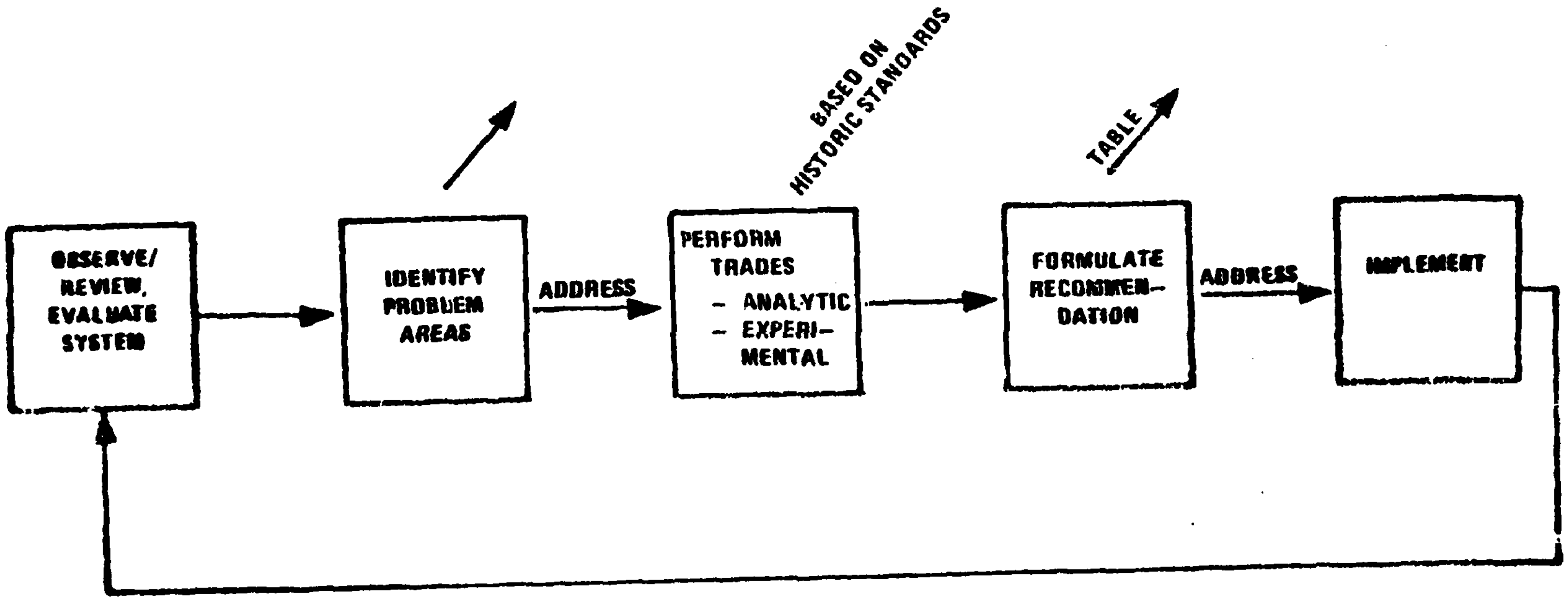

FIGURE 2-4. SOTAS HUMAN FACTORS PROCESS

As previously stated SOTAS was observed by Honeywell personnel during the Hunter-Liggett, San Diego, and White Sands tests and all REFORGER exercises from 1976 through 1979. More importantly than just observing these tests and exercises, they provided human factors objectives to be achieved during each exposure.

Using the process outlined in Figure 2-4, they provided system design recommendations that were duly considered by OPM SOTAS before proceeding to the next test or exercise. Those modifications that could be reasonably incorporated considering cost, schedule and/or hardware trade-offs were implemented. Other modifications deemed advisable, but with major cost or schedule impacts were delayed until full scale engineering development.

The SOTAS simulator was developed at Honeywell's Minneapolis facility and used continually for human factors studies and troop training. SOTAS is the only major system known to the study team in which the training device can truly be said to have evolved with the materiel and where there was a strong interaction between training developments, human factor design consideration, and hardware development.

Honeywell's approach to resolving human factor issues were threefold:[45]

- Continued analysis of and coordination with the ongoing engineering design activities
- Application of principles and conclusions derived from field and experimental data to guide the formulation of system concepts and design trade-offs
- Use of the SOTAS simulation facility to generate additional data to guide design trade-offs when gaps existed in the data base.

From the many examples of Honeywell human factor analysis available, three illustrative examples will serve to indicate the depth and breadth of methodologies applied to the SOTAS design.

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[45] D. G. Alden, Functional Specification of Man-Machine Interfaces for a Stand-Off Target Acquisition System (SOTAS), Final Report for Period November 1977 to May 1978. Honeywell Corporation, Minneapolis, MN: June 1978

The first example concerns personnel skills required to operate the system. Human factors test plans were developed for the San Diego test in 1975. The test demonstrated that the most important factor in selecting SOTAS crew personnel was the person's experience in the Army, not his MOS training. Honeywell concluded that E-6's and E-7's were required for the STO positions. This conclusion highlighted a career development problem, since the Military Personnel Center (MILPERCEN) requires a career progression for operators. What makes the SOTAS experience remarkable is that this problem was surfaced early in the demonstration and validation phase, rather than near the end of program development.

The second example concerns the van layout.[46] Field observations had indicated that certain layout variables can cause an impact on overall system performance. The more important of these variables selected for increasing overall performance were:

- Segregation of function by station
- Integration of work station
- Interactive distance
- Information-decision action proximity.

A full-scale mock-up reproduction and link[47] and visual[48] analyses were used to evaluate two alternative layouts. The evaluation and analyses of proposed designs resulted in an extensive system reconfiguration. It is interesting to note that both designs had implications on the role of the TSS. In the selected design the TSS was envisioned to be an information manager; the other design had him as a master console operator. Figures 2-2 and 2-3 represent the basic model posed for information flow on the selected van layout.

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46 Ibid, pp. 21-40.

47 Cf. A. Chapanis, Research Techniques in Human Engineering. Baltimore: The John Hopkins Press, 1962.

48 Cf. H. Von Cott and R. G. Kinbode (Eds.), Human Engineering Guide to Equipment Design. McGraw-Hill, Inc. New York: 1963.

The last example is an analysis[49] undertaken to reduce operator memory load and improve operator effectiveness by providing extensive cueing/prompting to reduce the complexity of operational procedures. Honeywell organized all of the functions required of SOTAS into a heirarchial tree structure that clustered conceptually related functions into common branches. A combination of functional keys and interactive dialogues were recommended for gaining access to the tree structure or switching heirarchy. Functional keys were designed to provide access to specific branches of the conceptual tree, while interactive menus were designed for complex branches to provide the operator with a set of options to guide him in completing the function. The system will be interactive and tutorial thus removing the memory load from the operator and transferring it to the computer system. This resulting design change for the engineering development model has the additional benefits of providing immediate feedback to the operator regarding the appropriateness of his action, reducing the complexity of initial training, reducing the requirement for refresher training, and reducing the skill levels required to operate the system. This latter benefit should help resolve the career development problem.

The three examples just presented were chosen for their applicability to the TOS program, as will be discussed below. As is evident from the above discussion, use of human resources data in the SOTAS program has been continuous from the onset. The emphasis has changed from more broad general objectives, e.g., functional analysis and simulation studies to narrower specific objectives, e.g., the design of the function keyboard. Now that an engineering development model is being fabricated, the emphasis has switched from system design considerations to training and doctrinal employment issues, although the former are still being addressed. Figure 2-5 is a recapitulation provided by Honeywell of the emphasis on human factors during the past five years. Most of the current emphasis is on secondary ground station manning requirements and the continual refinement of training.

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49 S. R. Hollingsworth and J. W. Wingert, Switching Hierarchy for SOTAS (U), Technical Report for the Period November 1978 - June 1979. Honeywell Corporation, Minneapolis, MN: June 1979. (CONFIDENTIAL)

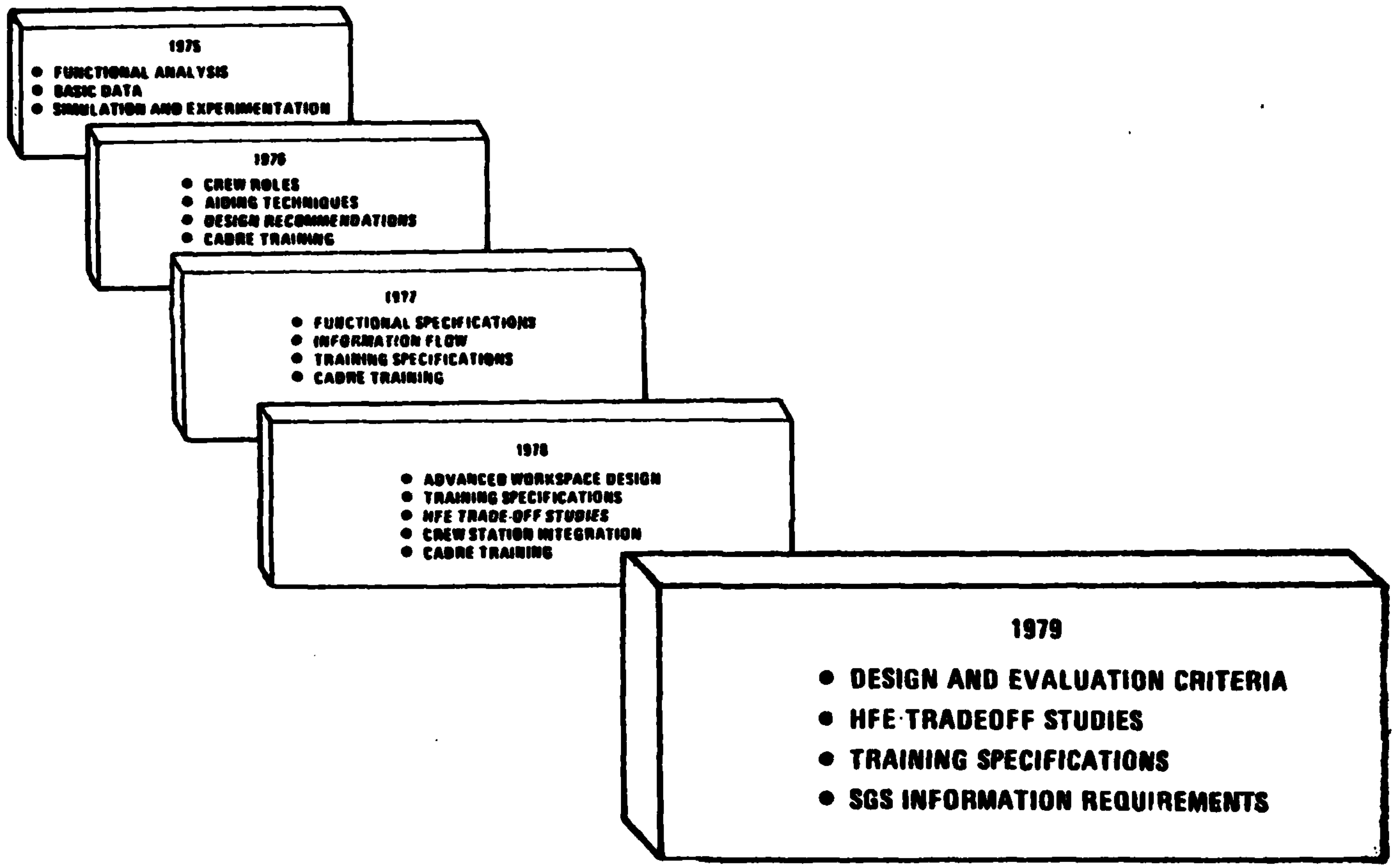

FIGURE 2-5. SOTAS HUMAN FACTORS FIVE YEAR EMPHASIS

2.3 XM1 ABRAMS TANK SYSTEM

In a parallel effort to this contract, SAI conducted a case study of the integration of personnel and training subsystems in the XM1 Abrams Tank System. This subsection discusses some selected topics from the XM1[50] experiences; for a full case study, see the XM1 study final report.

The XM1 Abrams Tank System is significantly different from the other systems reviewed in this study in several critical aspects. First, XM1 is a weapons system, rather than a C^3I system. As a weapons system its role on the battlefield is much better understood by the Army: kill and survive to kill again. The analysis and determination of end item and support requirements can be directly related to "bottomline" measures of effectiveness: lethality and survivability.

Second, XM1 is a replacement system, rather than a new battlefield concept. While XM1 is a significant technological improvement over the current M60 Series of main battle tanks, it is an improvement of degrees rather than a quantum leap. The basic organizational and operational concepts of the tank battalion will not undergo major changes as a result of the introduction of the XM1 into the inventory. This is in contrast to both TOS and SOTAS where the details of the system mission were often vague and changeable.

Third, XM1 was from its inception a very highly visible acquisition program. Close scrutiny at the highest levels of DA and DoD as well as in the Congress placed the system developers under unique pressures to meet cost and schedule constraints.

2.3.1 System Description

The XM1 Abrams Tanks will be a sophisticated, highly reliable, highly mobile, full-tracked armor fighting vehicle incorporating improvements in fire control, powerplant, suspension system, and armor protection. It will consist of a hull and a turret (fighting compartment) designed to maximize ease of operation and crew survivability.

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50 John J. Kane, Personnel and Training Subsystem Integration in an Armor System. Science Applications, Incorporated, McLean, VA: 12 January 1981.

The tank will be operated by a four-person crew: driver, gunner, loader, and tank commander, all trained in XM1-specific MOSs. At the organizational level, the tank will be maintained by an automotive repair technician (warrant officer), a tactical communications systems mechanic, a chassis/system mechanic, and a turret mechanic, the latter two being from XM1-specific MOSs. At the direct support/general support (DS/GS) level the XM1 will be maintained by the automotive repair technician and ten enlisted MOSs, half of which have XM1-specific special qualification identifiers (SQI) or additional skill identifiers (ASI).

The main gun is stabilized to the gunner's sight to allow accurate fire-on-the-move capability at relatively high cross-country speeds, a significant improvement over the current M60A1AOS and M60A3 tanks' fire-on-the-move capabilities. At the same time it poses additional training problems for the gunner, who must maintain a stablized sight picture while turret is moving about him. A ballistic computer system automatically solves sight parallax, lead, and superelevation problems.

The designers of the XM1 were faced with the dilemma in the weight/agility trade-off. The greater survivability of additional armor carries a penalty of more weight, which is in conflict with the goal of increasing survivability through more agility. Not only is a larger engine implied by heavier armor, it is also implied by more agility. However, a larger engine itself means more weight, which further aggrevates the problem. To make a major inroad in this constraint, the XM1 uses a gas turbine engine which can produce considerable saving in engine weight over a comparable diesel engine. Less engine weight can therefore be used for more armor. The standard idle allows the vehicle to move at a creep speed of 2.5 miles per hour for operations with dismounted infantry forces. The vehicle accelerates to twenty miles per hour in 6.2 seconds from idle and the maximum vehicle speed is governed to forty-five miles per hour. In spite of the engine's efficiency relative to other turbines it will use six to twenty-five percent more fuel than comparable diesel engines. A bonus of the turbine is its relative quiet and smokeless operation.

The suspension system features seven road wheel stations which allows each wheel to have a smaller diameter thus reducing the vehicle silhouette. High wheel travel gives the XM1 the capability to move cross country at high speed while still retaining control of the tank and being able to fire the gun.

Perhaps the biggest change in tank technology since the M60 was developed is the area of armor. The qualities of Special Armor are highly classified, however, it does increase the resistance to penetration. Spaced armor is also used in several places to protect key components. Compartmentalization of both fuel and ammunition further increases crew and critical components survivability.

The training device requirements of the XM1 were approved in late 1977 and are described in the paragraphs below. Recent changes to some support equipment concepts will lead to changes as yet undetermined in troubleshooting training reauirements area.

The Conduct of Fire Trainer (COFT) of One-Station Unit Training (OSUT) will allow one instructor to teach target acquisition, identification, and engagement to ten gunner positions, including the visual and audio feedback of the fire control equipment. Each station is individually controlled by a series of programs of varying difficulty according to trainee progress. The visual simulation is to provide a target scene of multiple and varied targets, as well as friendly equipment, with appropriate terrain and vegetation. The visual presentation will also be able to simulate the motion of the gunner's tank for fire-on-the-move training.

The driver trainer will allow one instructor to monitor five students at stations which duplicate the driver's compartment. Visual and audio simulations will provide the students "the illusion of driving the XM1 tank." The audio and visual feedback responds to control movements. The Unit Conduct of Fire Trainer (U-COFT) will be a shelter-mounted simulator to provide training in target acquisition, identification, and engagement with either primary or alternate fire control and fighting equipment in either the stablilized or the nonstabilized mode. Student actions will be monitored by an instructor station which replicates the students visual simulation and which can insert faults. The target scene will have the same requirements for realistic targets, terrain, and vegetation as OSUT-COFT.

The tank turret organizational maintenance trainer will facilitate student inspection, troubleshooting, installation, and removal, purging, and performance of proper organizational maintenance procedures, as contained in technical publications. The trainer will either use or faithfully simulate turret armaments, fire control systems, turret electrical systems, turret hydrolic systems and controls, elevating and traversing systems, stabilization system,

optics, wiring and control boxes, and intercoms and radios. The trainer will allow two faults to be simultaneously inserted which can be tested and corrected using the test equipment and tools specified in the organizational maintenance manual. Troubleshooting simulators will allow the instructor to demonstrate and for the student to practice troubleshooting the system. They include actual controls, fluid flows, electrical current flows, and auditory cues as appropriate to simulate normal operation and operation with easily inserted faults. Actual or simulated diagnostic equipment provides readout appropriate to either normal operation or the simulated fault. These simulators will record and score student performance. Troubleshooting simulators will be provided for: X1100-3B Transmission Hull Electrical SYstem, Turbine Engine, Laser Range Finder, Ballistic Computer, Thermal Site, and Direct Support (DS)/General Support (GS) Turret Trainer.

2.3.2 XM1: Selected HRD Topics

2.3.2.1 Human Factors Engineering (HFE)

In both the Advanced Development (AD) and Full Scale Engineering Development (FSED) phase, responsibility for HFE was vested primarily in the contractor hardware developers. During AD there were two competing contractors (Chrysler Corporation and General Motors Corporation) whose plans were closely guarded as proprietary; during FSED there was a single contractor (Chrysler). Little information is still extant concerning the AD phase HFE. An analysis by HEL and the US Army Medical Research and Development Command (MRDC) provides a good review of the FSED phase.[51]

Chrysler created an HFE/System Safety (SS) Group to monitor and provide guidance for the HFE program. HEL characterized the HFE/SS personnel as "highly qualified (both academically and experientially) individuals whose combined skills have been effectively utilized from the earliest conceptual stages of the XM1 program." The HFE program iteself was described as "generally, comprehensive and effective."[52]

[51] HEL/MRDC, Human Factors Engineering Analysis for XM1 Tank System ASARC III. Aberdeen Proving Ground, MD: 10 January 1979.

[52] Ibid., p. 6.

As an aid to the design engineers, the HFE/SS Group published an HFE and safety design guide.[53] This book provided a convenient summary of HFE-related requirements and criteria. Its purpose was to assist in producing a better and more uniform design from the human factors standpoint.

HEL noted, however, that "there were a few areas where it appears that HFE considerations which significantly affect the operational suitability of the vehicle were overruled by cost reduction changes."[54] They also noted that the HFE/SS group had difficulty in gaining access to a mated hull and turret mock-up and to prototype vehicles, due to tight work schedules and cost constraints. This hampered their ability to gain hands-on experience and to demonstrate some man-machine interfaces.

The HEL/MRDC report was prepared to support the ASARC III decision. A list of topics considered is shown in Figure 2-6.

2.3.2.2 Training Device Requirements (TDRs)

The development of XM1 system training devices was delayed for over three years due to difficulties in defining TDRs. Two competing training device concepts were considered. One called for an essentially traditional approach to armor training, emphasizing the use of operational equipment and relatively low development and procurement costs. The other approach would employ high fidelity simulators at relatively high development and procurement costs, but held out the possibility of lower operating and support costs.

The considerable delay in establishing TDRs resulted from an inability to chose between the two approaches in an objective fashion. The new, high technology simulators were generally still in the conceptual design phase, and thus could not be validated by empirical data.

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53 Chrysler Corporation, Human Factors Engineering and Safety Design Guide. Sterling Defense Division, Sterling Heights, MI: 15 January 1978.

54 HEL/MRDC, op. cit., p. 6.

Contractor Program

- Program Effectiveness
- Task Analysis

Environment and Environmental Safety

- Noise
- Heating and Ventilation
- Toxicity
- Shock and Vibration
- Laser Rangefinder Safety

Crew Work Space

- Ingress/Egress
- Geometry and Seating
- Controls/Displays

Vision and Night Operations

Rearming

Nuclear, Biological, and Chemical Survivability

Crew Maintenance

Training Analysis

FIGURE 2-6. TOPICS CONSIDERED BY THE HEL/MRDC HFE ANALYSIS

The major analytic effort conducted during the development of the TDRs was a Cost and Training Effectiveness Anlaysis (CTEA) of the crew training devices conducted by BDM Services Company (BDMSC).[55] This study contained a detailed analysis of alternative COFTs and a cursory cost analysis of a Driver Trainer and a Full Crew Interaction Simulator. No analysis was conducted of any training devices for maintainence.

The primary analytical tool used to examine training effectiveness was the TRAINVICE model, originally developed by the American Institutes for Research for ARI.[56] The model had previously been applied to two non-system devices[57, 58] and has since been

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[55] William Elliot, et. al., Cost and Training Effectiveness Analysis for XM-1 Tank Training Devices, BDM/CARAF-TR-76-037. BDMSC, Fort Leavenworth, KS: February 1977. (2 volumes)

[56] G.R. Wheaton, et. al., Evaluation of the Effectiveness of Training Devices, Research Memorandum 76-16. USARI, Alexandria, VA: 1976.

[57] John J. Kane, et. al., Panoramic Moving Target Screen (PMTS) Cost and Operational/Training Effectiveness Analysis (COEA), BDM/CARAF-TR-76-064. BDMSC, Fort Leavenworth, KS: September 1976. (2 volumes)

[58] John J. Kane, et. al, Remoted Target System--Non-System Training Device (RETS) Cost and Operational/Training Effectiveness (COEA), BDM/CARAF-TR-76-065. BDMSC, Fort Leavenworth KS: September 1976.

applied to a variety of programs.[59, 60, 61, 62] The model has since been modified by ARI.[63]

TRAINVICE is an analytic method which results in a quantitative index of "training transfer" as a figure of merit. The index is developed through analyses of the coverage of critical tasks, the physical and functional similarity of training tasks to operational tasks, and the appropriateness of the learning techniques applied. The TRAINVICE index provides only a relative figure of merit, i.e., while it is useful for comparing two devices to one another, it provides no estimate of the actual training impact.

2.3.2.3 Annual Maintenance Man Hours (AMMH)

A critical data input to the QQPRI is the AMMH, from which the requirement for maintenance personnel are determined. The XM1 program experienced many difficulties in establishing AMMH and even now, nearly two years after ASARC III, an adequate database for determining AMMH is lacking.

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59 John J. Kane, et. al., Ground/Vehicular Laser Locator Designator (G/VLLD) Cost and Training Effectiveness Analysis (CTEA): Phase I Report, Volume I, BDM/W-78-058-TR. BDM Corporation, McLean, VA: 13 February 1978.

60 R.W. Swezey, et. al., Implications for TOW Gunnery Training Developments. Mellonics Systems Development Division, Springfield, VA: 1977.

61 R.W. Swezey, et. al., Implications for Dragon Gunnery Training Developments. Mellonics Systems Development Division, Springfield, VA: 1977.

62 W.B. Stewart and D.M. Kelley, Cost and Training Effectiveness Analysis for Stand-Off Target Acquisition Surveillance System, Pub. 1979-01-1-1650. ARINC Research Corporation, Santa Ana, CA: September 1977.

63 R.W. Swezey and R.A. Evans, Guidebook for Users of TRAINVICE II (Draft), SAI-80-065. Science Applications, Inc., McLean, VA: May 1980.

Fairly early in the program it was determined that the appropriate RAM data would not be collected during DT/OT I, but would wait for DT/OT II.[64] As an interim measure, data from the Army's field experience with the M60A1 and M60A2 and projections for the M60A3 were used.

Plans to collect AMMH data during OT II went awry when problems developed in keeping the test vehicles running. Hardware problems resulted in major modifications to the end item during the test as well as frequent contractor intervention in the test maintenance.[65] Data was also collected at a Physical Teardown/ Maintenance Evaluation (PT/ME), but was rejected later as unrepresentative. In an attempt to develop new AMMH for ASARC III, PM XM1 convened a Maintenance Data Evaluation Workshop, which employed a Delphi Approach. The Project Management Office (PMO), however, declared that there were too many problems with the basic data and that the workshop was a failure.[66] The PMO proposed:

> "It is recommended that consideration be given to initially fielding the XM1 using current TOE [Table of Organization and Equipment] authorizations for personnel. After a period of field experience, AMMH could then be computed based on actual data and used to amend TOE'S."[67]

A final QQPRI was not approved by HQDA. A Final MOS Decision was established by MILPERCEN, but with a proviso that an Amended Final MOS Decision would be required. Data to determine AMMH is now scheduled to be collected at DT/OT III.

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64 W.C. Kietzman, et. al., Developmental Test I of XM1 Tank System (U): Test Plan Final Draft. USATECOM, Aberdeen Proving Ground, MD: April 1975, p. 3. (SECRET)

65 Logistics Evaluation Agency, XM1 Tank ILS Program: Interim Assessment. New Cumberland, PA: 2 January 1979.

66 Msg. 151230Z from PMO XM1 to TSM XM1, ATZK-XM1, dated 15 December 1978. Subject: XM1 Logistic Support Analysis Records (LSAR).

67 Ibid.

SECTION III

APPLICATION OF HUMAN RESOURCES DATA IN SYSTEM DEVELOPMENT

The purpose of this section is to consider the range of various methods which have been used in incorporating HRD considerations into system development. Among those issues to be examined in the following sections are:

- How are HRD defined?
- What HRD methodologies are most useful for system development?
- At what phase in system development should the various HRD elements be applied?
- How can the use of HRD tradeoff analysis during the system development be useful for human engineering purposes?
- What kinds of human factors testing procedures should be employed to evaluate system design?
- What needs to be done to improve the feasibility and effectiveness of HRD utilization in system design?

3.1 DEFINITION OF HUMAN RESOURCES DATA

During the initial analysis, it became apparent that human resources data, as they relate to this effort, are not wholly defined. Terms frequently appearing in the literature relative to human resources data include: human engineering data, human resources engineering, and human factors engineering (HFE). These terms are often used synonymously, although shades of difference in definition among the terms appear in most studies. AR 602-1 provides a definition which states that HFE is a "comprehensive technical effort to integrate all personnel characteristics (skills, training implications, behavioral reactions, human performance, anthropometric data and biomedical factors) into Army doctrine and systems to assure

operational effectiveness, safety, and freedom from health hazards."[1] This regulation states that HFE includes:

- That part of system analysis that determines the personnel role in a personnel-materiel system
- Selecting, defining, and developing personnel-materiel interface characteristics, workspace layout, and work environment conducive to effective and efficient performance under expected use conditions (The process of developing and defining such a work environment includes a detailed analysis of the impact of the proposed environment on the health and well-being of operator and maintenance personnel.)
- Coordination with other agencies in determining the needs for and then developing and evaluating job procedures, performance aids, and training devices, aids, equipment, and technical publications
- Providing basic personnel-materiel task sequence data used to describe, develop, and assess the feasibility of the soldier performance required in a personnel-materiel system
- Developing equipment which permits effective personnel-materiel interaction under special limitations in the training time, aptitudes, skills, or physical standards
- Determining the number and kinds of military and civilian personnel needed in a personnel-materiel system to evaluate the relative effectiveness of design concepts and for subsequent personnel planning, and providing the data needed for modifying current MOSs or establishing new MOSs required by new equipment, doctrine, or organization

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1 AR 602-1, Personnel-Materiel Systems Human Factors Engineering Program, June 1, 1976.

- Assessing the training burden which competing materiel design concepts may impose on the Army

- Developing the information needed for new or revised training plans, courses, or programs of instructions as required by new or modified materiel, doctrine, or organization

- Confirming the effectiveness of the program by evaluating the completed personnel-materiel system

- Conducting research required to resolve personnel related problems encountered in materiel development programs, as disclosed through systems analysis in the first bullet above.

The regulation goes on to define the objectives of the HFE program as follows:

- Assure that Army materiel and concepts of its use conform with the capabilities and limitations of the fully equipped soldier to operate, maintain, supply, and transport the materiel in its operations environment, consistent with tactical requirements and logistic capabilities

- Insure that materiel is developed so that the personnel tasks involved in its operation, maintenance, supply, and transport do not exceed the capabilities of the soldier

- Assist the Army trainer in achieving an effective, sufficient, necessary, and integrated Army training program

- Improve control of total life cycle costs of personnel-materiel systems by assuring consideration of the costs of personnel resources and training for alternative systems during the conceptual stages and for the selected system during subsequent stages

- Optimize the relationship between skill levels, training, and personnel required to operate and maintain

- Assure that equipment designs are compatible with the capabilities and limitations of the personnel who must operate and maintain them through basic and applied studies and research, personnel-materiel system analysis, and psychophysiology

- Develop data defining the existing range of human performance, comparing them against systems performance requirements, to identify new performance requirements, and provide for the timely development of the necessary trained personnel resources

- Insure that systems engineering considers safety and health standards

- Provide data for the development of technical manuals, training manuals, field manuals, and other technical publications and insure that the use of these publications does not require aptitudes, education, or training beyond that required to perform the tasks they describe

- Apply human factors engineering concepts and current educational technology to design and development of training devices and aids.

From another perspective, Prokuski defines human factors engineering as a concept consisting of a "systematic and integrated approach to providing timely products and processes necessary for optimizing the man-machine relationship."[2] In military applications, Prokuski applies the term to those "engineering and management tasks required to provide for effective human performance..."[3]

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2 Bronislaw Prokuski, Human Factors Engineering in Air Force Weapon Systems Acquisition, Program Management Course Individual Study Program, Defense Systems Management College, Study Project Report PMC 77-1, May 1977, p. 5-6.

3 Prokuski, op. cit., p. 5-9.

A more generic definition for human resources provided by Askren suggests that "...human resources may be likened to the other resources of the organization such as equipment, facilities, land, raw material, etc., which can be drawn upon to accomplish the purpose of the organization...human resources data...are those data which describe the people of an organization in terms of what they can contribute, how much they cost, how available they are, how perishable they are, and how many of them are needed."[4]

Using Prokuski's approach, five basic elements of human resources data, were identified:

- Manpower and personnel requirements
- Biomedical
- Maintenance
- Training
- Human factors test and evaluation.

These elements require emphasis by both engineering and management disciplines and suggest that a complete set of human resources data must include man's function in the system. More specifically, each of these elements can be operationally defined as:

- The manpower and personnel requirements element is concerned with the number of trained personnel required to operate, maintain, control, and support the system equipment in its operational environment.
- The biomedical element includes areas which require provisions for the promotion of health and safety of all personnel who operate and/or maintain the system equipment.

[4] William B. Askren, Human Resources and Personnel Cost Data in System Design Tradeoffs: And How to Increase Design Engineer Use of Human Data, Technical Report-AFHRL-TR-73-46. Air Force Human Resources Laboratory: October, 1973, pp. 5-6.

- The maintenance element is concerned with predicting manpower requirements during system development. Methods used should consider maintenance task data to provide early estimates of manpower requirements for use in making system tradeoffs.

- The training element includes all training supplied to personnel who operate and maintain the system. This element has four subelements: system trained personnel requirements, training plan, training equipment development, training support data.

- The human factors test and evaluation element should determine whether personnel with system training and system peculiar tools can operate, maintain, control, and support the system in its intended operational environment.

Based on these considerations, human resources data can be defined as that human engineering, human factors, and human resources information which is used at various stages of the system acquisition cycle to insure the optimum interface between system hardware, software, and personnel. Human resources data includes all engineering and human support technologies that must be used to make certain that a system is optimally operated and maintained in tactical environments. Proper use of these data should include a concern for "what data" is used "when in the system acquisition cycle," to "what extent" is it used, "what role" it plays in system design and development, and "how much" management emphasis/priority is placed on its use. Priorities should place emphasis on designing systems with proper consideration for human functions and roles--rather than engineering systems first and then attempting to make humans fit the system.

After focusing on each separate HRD element and available methods which apply these elements to system development, this section will investigate existing technologies which seek to integrate manpower, biomedical, maintenance, and training HRD elements. An integrated systems technology must consider all HRD elements in the optimal unification of hardware, software, and personnel.

Conclusions regarding the impact of HRD methodologies in system development will be made indicating technological areas which need to be improved upon or further developed to increase the feasibility and effectiveness of applying HRD in the system development process.

Although it is not the purpose of this section to provide an in-depth discussion of methods of deriving HRD, the basic principles involved should be discussed since they serve to identify the type of HRD to be considered in the designing of systems.

Systems analyses can be described as having the following general purposes (Kidd and Van Cott, 1972):[5]

1. To identify all of the system requirements and the logical and sequential order in which they must be accomplished

2. Identify limiting factors which serve as potential constraints including environmental, hardware, information acquisition, flow factors, personnel problems, and costs

3. To establish system performance criteria to serve as standards for both designing and testing the system

4. To identify and explicate design options enabling the designer to decide on man/machine utilization

5. To select system and subsystem performance measures prerequisite to the test and evaluation of the systems.

Successfully integrating HRD concerns throughout the stages of system development will assist in the designing of an environment and man-machine interface which contribute to man's successful and efficient performance within the system.

An analysis of system functions serves to define all operations or activities which contribute to the system's goal or mission. One level of analysis, the functional analysis, serves to determine gross system functions on the basis of system requirements. The purpose of the functional analysis is to examine possible alternative combinations of functions which contribute to the successful completion of the mission.

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[5] Jerry S. Kidd and Harold P. Van Cott, "System and Human Engineering Analyses," in Human Engineering Guide to Equipment Design, Harold P. Van Cott and Robert G. Kinkade, Eds. US Government Printing Office: Washington, DC, 1972.

At a finer level of detail, the task analysis specifies the nature of performance required of human operators. This analysis results in information concerning stimulus and response behavior and the prerequisite skills and knowledges necessary for successful task completion. Several extensions of task analysis include time-line analysis and sequential analysis. Time-line analysis provides information regarding periods of peak personnel and equipment workloads and situations resulting in conflicting demands upon personnel or equipment. Sequential analysis is useful in delineating the sequential distribution of operations, tracing the information flow, and providing indications of the functional relationships between system elements.

Various methods of system analysis can serve to identify both qualitative and quantitative HRD considerations impacting on man's performance in the system.

3.2 MANPOWER AND PERSONNEL

In designing systems which consider manpower and personnel HRD, the first step is the projection of manpower requirements. The projection of manpower requirements is initiated with the allocation of man/machine functions. Before an assessment can be made of the skills and abilities required of persons who operate and maintain the system, decisions must be made regarding which functions will be performed by men and which will be performed by machines. Chapanis (1965)[6] proposes a strategy for making man/machine functional allocations. His approach is outlined as follows:

1) Prepare a complete and detailed system

2) Analyze and list system functions

3) Make tentative assignments for each function

4) Evaluate the sum total of functions which have been assigned to man.

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6 Alphonse Chapanis, "On the Allocation of functions between men and machines," Occupational Psychology, 1965, 39 (1), p. 1-11.

Table 3-1 (Chapanis, 1965)[7] lists relative capabilities of men and machines.

In a study related to the manpower and pesonnel dimension of HRD, Meister et al.'s (1969)[8] research for the Air Force Human Resources Laboratory sought to determine what differential effects occur as a result of applying different amounts of HRD during various times over the systems development cycle. The main purpose of the research was to study the effects upon system design when personnel quantity and quality requirements are varied. The experiment was designed to analyze these two parameters utilizing eight design engineers as subjects for the study. Conditions of the experiment included a number of engineering design solutions as a function of the HRD input at various times during system design; i.e., the study sought to determine whether the time of HRD inputs made any differences relative to system design options.

In this study the authors noted that HRD manpower requirements should have a direct influence on system design. Meister defines manpower requirements as the maximum number and skill levels of personnel for whom the system is being designed. These considerations should require the systems engineer to design a system that would meet these requirements. The supporting data necessary for an early assessment of manpower requirements is shown in Table 3-2. (Meister et al., 1969)[9]

The results of this study suggested that the amount and timing of HRD inputs do produce some impact on the engineer's design. Specifically, various personnel requirement constraints affected design decisions. Additionally, <u>type</u> of manpower requirements constraints versus personnel numbers create enlightened attitudes toward the utilization of this kind of data in the system design process. The most significant aspect of the study, from the HRD perspective, was that if HRD are to be used in the system design, they must be introduced during the <u>initial stages of design</u>, and should be written as design requirements.

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7 <u>Ibid</u>.

8 David Meister, Dennis J. Sullivan, Dorothy L. Finley, and William B. Askren. <u>The Effect of Amount and Timing of Human Resources Data on Subsystem Design</u>, Technical Report No. AFHRL-TR-69-22. Air Force Human Resources Laboratory: October 1969.

9 <u>Ibid</u>.

TABLE 3-1: A HIGHLY ABBREVIATED LIST OF SOME OF THE RELATIVE ADVANTAGES AND DISADVANTAGES OF MEN AND MACHINE

MEN	MACHINES
Able to handle low probability alternatives, i.e., unexpected events.	Difficult to program. Difficult to anticipate all possible events and so virtually impossible to program for all such contingencies.
Able to perceive, i.e., to make use of spatial and temporal redundancies and so to organize many small bits of information into meaningful and related "wholes."	Zero, or very limited, ability to perceive. "Organization" has to be elaborately programmed, which is difficult to do because of the many alternative ways organization can be formed from elements.
Possess alternative modes of operation. Can accomplish same or similar results by alternative means if primary means fail or are damaged.	Alternative modes of operation limited. May break down completely when partial injury or damage occurs. Not able to regenerate or heal.
Limited channel capacity, i.e., there is a maximum amount of information that can be handled per one time, and this is small.	Channel capacity can be made almost as large as desired.
Performance subject to detrement over fairly short time periods, because of fatigue, boredom, and distraction.	Behavior decrements only over relatively long periods of time.
Comparatively slow and poor computers.	Excellent and very rapid computers.
Flexible: can change programming easily and frequently. Very large number of programs possible.	Relatively inflexible. Flexibility in kind and number of programs can be achieved only at a great price.

TABLE 3-2

LIST AND DEFINITION OF
HUMAN RESOURCES DATA INPUTS

I. MANPOWER REQUIREMENTS

Item	Definition
(1) Number of personnel	Quantity of personnel required to perform subsystem operations, defined in terms of maximum number allowed.
(2) Skill level	Skill levels allowed for the task.

II. SUPPORT DATA

Item	Definition
(1) Lists of personnel tasks	Tasks defined in terms of personnel functions and equipment acted upon.
(2) Personnel/equipment flow	Diagrams illustrating the sequencing and interrelationships among tasks.
(3) Personnel/equipment analyses	Description of equipment characteristics required by tasks or effect of equipment characteristics on task performance.
(4) QQPRI Data including:	
(a) Proficiency	Skill characteristics which personnel should possess to perform the job satisfactorily.
(b) Skill type	Characteristics of the job to be performed in terms of demands upon personnel.
(c) Personnel availability	Definitions of US Air Force Systems Command (AFSC) type possessing necessary qualifications to perform the job, together with the probability of such personnel being available for the job.

TABLE 3-2 (Cont.)

LIST AND DEFINITION OF
HUMAN RESOURCES DATA INPUTS

(5)	Training requirements, including:	
	(a) Anticipated training time	Time needed to train to given level of proficiency.
	(b) Required aptitude	Job skills which training should provide.
(6)	Task analysis, including:	
	(a) Task structure	Task description in terms of function and equipment operated or maintained (See Item II (1)).
	(b) Task criticality	Consequences of task being performed incorrectly or not at all.
	(c) Team performance	Number of personnel required to perform the task.
	(d) Probability of successful task completion	Quantitative estimate of probability that the task will be completed successfully by personnel (the converse, error probability, also is provided).
	(e) Task location	Approximate physical area (e.g., flight line, shop) in which the task must be performed.
	(f) Task duration	Estimate of the time required to perform a task.
	(g) Difficulty index	Estimated difficulty of task defined in terms of error probability and response time.
(7)	Time-line analysis, including task frequency	Distribution over time, including overlaps, of individual task durations.

Another study by Eckstrand (1972)[10] examined the effectiveness of using manpower and personnel resources data as design requirements and determined under what conditions these inputs can have maximum influence on system configuration. Given equipment specifications and hardware information, design engineers were given a manpower constraint which required them not to exceed a certain crew size and skill level. They were also given HRD inputs such as task analyses, training requirements, and time-line analyses. Engineers were asked to design equipment so that it could be operated and maintained by a specific number and type of personnel.

It was found that HRD inputs must be supplied to the engineer in the Statment of Work (SOW), and must be understandable in terms of the design implications of the HRD inputs. It was concluded that HRD inputs do influence system design, but engineers resist the concept that HRD analyses are a part of the control subsystem design.

A method of applying manpower and personnel HRD data that has proven effective in improving development decision correctness is the use of HRD handbooks. Meister (1976)[11] used an HRD handbook developed by the Air Force Human Resources Laboratory which included manpower and personnel data and examined the effectiveness of the handbook to assist users in solving hypothetical or simulated system development problems. The results of this study indicated that systems development personnel were able to use the HRD handbook to improve the correctness of their development decisions. Respondents generally felt that the handbook had some utility in influencing design, and Meister, therefore, recommended further development of HRD handbooks as a design tool for systems engineers.

Another concern regarding the incorporation of manpower and personnel HRD in system development is to ensure the proper selection of personnel with the necessary ability to be able to operate the system effectively. Valid testing and evaluation cannot be conducted unless qualified personnel are selected to man the system. The Army Classification Battery (ACB) provides measures of trainability in MOSs. The most basic kinds of information which impact on decisions made during the classification process are the aptitudes and abilities

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[10] Gordon A. Eckstrand, Human Resources Consideration in the Development of Complex Systems, Technical Report--AFHRL-TR-72-64. Air Force Human Resources Laboratory: September 1972.

[11] David Meister, Assessment of a Prototype Human Resources Data Handbook for Systems Engineering, Technical Report, AFHRL-TR-76-92. Air Force Human Resources Laboratory: December 1976.

of the men and the manpower needs of the Army. It is necessary to match the aptitudes and abilities of the available manpower to meet the manpower needs of the system. Table 3.3 (Maier and Fuchs, 1972)[12] shows the tests which form the aptitude area composites for the ACB. Each composite includes tests which measure the aptitudes and abilities important for a particular MOS. The ACB provides information about aptitudes and abilities and the Army requirements are determined by set quotas for each MOS. The capabilities of the individuals are matched to the demands of the MOS so that the aptitudes and abilities of manpower are used to the best advantage.

However, when considering effective manpower utilization in developing systems, it may be necessary to reanalyze existing tests to make sure that they are selecting the most qualified personnel to operate the system. It may be necessary to design the system down to meet minimum skill level requirements based on manpower availability constraints, but the types of testing used in the selection process should be valid and reliable measures of abilities required of system operators. Care should be taken that proper specification of MOS be made in assigning personnel to test the operational effectiveness of newly developed systems. New aptitude area composites or MOSs may need to be developed or refined to more accurately describe the ability requirements of manpower serving the system.

In summary, methods which apply manpower and personnel HRD data to system development are concerned with the early projection of manpower requirements--specifically numbers and skill levels. Manpower and personnel HRD requirements should be introduced during the initial stages of system design to have maximum influence on system configurations. It has been determined that the use of HRD handbooks can serve as a design tool for system engineers and improve the correctness of system development decisions. Personnel must be selected with the necessary skills and abilities to provide valid tests of the system's operational effectiveness.

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[12] Milton H. Maier and Edmund F. Fuchs, An Improved Differential Army Classification System, TRR 1177. Behavioral Sciences Research Laboratory, Alexandria, VA: April 1972.

TABLE 3-3

NEW APTITUDE AREA COMPOSITES

TEST		APTITUDE AREA COMPOSITES									
General Ability Tests		CO	FA	EL	OF	SC	MM	GM	CL	ST	GT[a]
Arithmetic Reasoning	(AR)	AR	AR	AR		AR		AR	AR	AR	AR
General Information	(GI)		GI		GI						
Mathematics Knowledge	(MK)		MK				MK			MK	
Word Knowledge	(WK)					WK			WK		WK
Science Knowledge	(SK)							SK		SK	
Mechanical Ability Tests											
Trade Information	(TI)	TI		TI			TI				
Electronics Information	(EI)		EI	EI			EI				
Mechanical Comprehension	(MC)			MC		MC		MC			
Automotive Information	(AI)				AI		AI	AI			
Perceptual Ability											
Pattern Analysis	(PA)	PA				PA					
Attention-to-Detail	(AD)	AD							AD		
Auditory Perception	(AP)					AP					
Classification Inventory											
Combat Scale	(CC)	CC									
Attentiveness Scale	(CA)		CA		CA				CA		
Electronics Scale	(CE)			CE							
Maintenance Scale	(CM)						CM				

Symbols: Aptitude Area Composites

CO = Combat
FA = Field Artillery
EL = Electronics Repair
OF = Operators and Food
SC = Surveillance and Communications

MM = Mechanical Maintenance
GM = General Maintenance
CL = Clerical
ST = Skilled Technical

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[a] GT used only to determine who is qualified to take additional tests such as the Officer Candidate Test.

3.3. BIOMEDICAL

In examining methods of applying biomedical HRD, all subsystems must be examined to identify sources of hazard which would adversely effect the health and safety of personnel. A study conducted by HEL and MRDC (1979)[13] used a Human Factors Engineering Analysis (HFEA) in support of the XM1 ASARC III in order to:

- Identify those areas where the man-machine interface is limiting overall system performance
- Identify vehicle characteristics which may prove to be physiologically harmful to the crew
- Recommend corrective actions or further investigations where appropriate.

This research was conducted jointly by HEL and MRDC, with the assistance of the Army Health Services Command (HSC). A complete analysis and recommendations are provided in areas of environment and environmental safety; crew work space; vision and night operations; rearming; nuclear, biological, and chemical (NBC) survivability; crew maintenance; and training devices. Each system entity impacting on operator health and safety was analyzed in accordance with structured military requirements designed to fulfill program objectives. An analysis was conducted to ensure adequate consideration of HFE factors in the numerous trade-offs which need to be made in the design of the combat vehicle. For example, one of the recommendations resulting from the noise analysis was to specify by means of warning placards that protective hearing gear be worn whenever the vehicle is operating. In order to provide an organizing framework to assist the human factors engineer, a Human Factor Engineering and Safety Design Guide was published to summarize all the human factors engineering and system-related design requirements.

Various methods are available to examine the impact of applying human factors data in the designing of equipment and crew workspace. It is unfortunate that these human factors considerations are frequently not considered early enough to have maximum impact on

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[13] HEL/MRDC, Human Factors Engineering Analysis for XM1 System ASARC III. Aberdeen Proving Ground, MD: January, 1979.

system design. Meister et al's (1969)[14] study determined that among various types of HRD inputs considered during predesign and detailed design states, the designing of equipment required by personnel characteristics or tasks was a low priority HRD input.

The Human Engineering Guide To Equipment Design sponsored by the Joint Army-Navy-Air Force Steering Committee (Van Cott and Kinkade, 1972) discusses the proper design of controls, individual workplaces, and multi-man-machine work areas in order to encourage and preserve the user's physiological health. This involves considering problems and constraints resulting from physical and behavioral variations among men and the structural and functional limitations of man. The information presented in this guide is of use in the application of biomedical types of HRD during system development.

Numerous studies have been devoted to examining the stresses effecting soldiers in combat. A literature review intended to relate stressors associated with continuous Army operations with human performance was conducted by Pfeiffer and Associates (1979).[15] Variables such as vision, hearing, strength, sleep loss, heat, cold communications, etc. and their effects on performance are discussed. A taxonomy of performance abilities is provided in the report and a description of those factors or conditions unique to continuous operations. A list of tasks critical to the attainment of specific mission goals was formulated for each of the five members of a mechanized infantry fighting squad and categorized according to the ability taxonomy. A comparison volume serves as a guidebook which identifies performance limitations on the basis of relationships between impacting variables and the performance taxonomy.[16] Table 3-4 (Pfeiffer et al., 1979) shows the type of data generated from the literature review, pertaining to performance documents in various environmental conditions.

Pfeiffer also discusses the problems asociated with deriving biomedical HRD and distinguishes between the psychological and physiological limits of toleration to stress. He defines the

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14 Meister, Sullivan, et al, op. cit.

15 Mark G. Kubala, Arthur I. Siegel, Stanley E. Taylor, and Lucius Shuler, Jr. Background Data for the Human Performance in Continuous Operations Guidelines, Technical Report 386. Army Research Institute, Alexandria, VA: July 1979.

16 Ibid.

TABLE 3-4. SUMMARY OF LITERATURE CONCERNING PERFORMANCE DETERIORATION AS THE RESULT OF ENVIRONMENTAL CONDITIONS.

Condition of Environment	Point of Deterioration in Performance	Task	Type of Performance Deterioration	Reason	Reference
Dim light	Full moon	Speaking face to face	Reduced understanding	Fewer visual cues present	Kryter, 1972 (p.190) Chapanis, 1971
Dim light	5 Ft-L of light	Reading news type & italics	Reduced speed	Some details not visible	Tinker, 1943, 1952
Dim light	Depends upon experience with terrain	Memory for movement through underground maze	Reduced sense of direction	Poor memory or lack of training	Kozlowski & Bryant, 1977
Twilight	100% contrast of target needed to achieve 99% detection probability	Detecting targets of unknown location	Failure to detect target	Insufficient contrast to guarantee detection	IES Lighting Handbook, 1972 Crouch, 1958 Blackwell, 1946
Full moon	10,000% contrast of target needed to achieve 99% detection probability	Detecting targets of unknown loca-	Failure to detect target	Insufficient contrast to guarantee detection	IES Lighting Handbook, 1972 Crouch, 1958 Blackwell, 1946
Low contrast ratio=5% (over cast day)	Object must subtend 3 min. of visual angle to be seen with 100 Ft-L of light	Visual detection	Loss of visual acuity	Low contrast ratio	Cobb & Moss, 1928
Low contrast ratio=5% (rainy day)	Object must subtend 5 min. of visual angle to be seen with 1 Ft-L of light	Visual detection	Loss of visual acuity	Low contrast ratio	Cobb, & Moss, 1928
Night Ganzfeld, e.g., fog at night	No cues available	Accommodation of lens of eye	No visual acuity for distant objects	Loss of accommodative function	Le Grand, 1967
Night driving without street lights	Large individual differences will require screening	Driving	Myopia	Occular accommodation toward resting or dark focus	Leibowitz & Owens, 1977

psychological limit as being the level beyond which performance is unsatisfactory; stress exceeding physiological limits would cause irreparable tissue damage. Systems should be designed and mission goals established which do not result in permanent negative consequences to the soldier's health by exposure to severe environmental stressors. Research designed to measure physiological and psychological limits is difficult because of the dangers of inflicting permanent tissue damage on experimental subjects. Research conducted on animals when generalized to the human populus does not permit accurate specification of tolerance limits. Requirements for the design of experimental research relating to human ability and environmental stress include:

- different levels of exposure to environmental stress for different time periods
- determining the response of the subject to environmental stress
- determining responses of each subsystem of the organism to severe environmental stress.

"Since data are both lacking and difficult to obtain near the upper limits of human tolerance, modeling techniques and computer simulation may be required to predict the effect of severe environments on performance (Pfeiffer, 1979)."[17] A multitude of stressors--both psychological and physiological--confront the soldier in combat. Existing research on the performance effects of stress have been minimal, and existing research findings conflicting (Kubala, 1979).[18] Much of the available research is not relevant to the combat situation. There is a need for further studies which examine the interactions among stressors; for example, it is possible that additive and subtractive effects occur causing two or more environmental stressors to combine to cancel each other out or enhance each other. Until improved methods are derived for generating this type of HRD and more conclusive evidence is gathered, these concerns will not have a heavy influence in system design.

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17 Ibid.

18 Kubala, op. cit.

19 William Baumgartner, Human Factors Engineering Considerations in Designing Naval Aircraft for Maintainability, Thesis, Naval Postgraduate School, June 1977.

3.4 MAINTENANCE

The rising maintenance costs and emphasis on increased availability of Naval air systems led Baumgartner (1977)[19] to conduct a study of the human factors engineering as a design parameter leading to improved aircraft maintainability. One of the major results of this study was a check list developed by Baumgartner to be used by aircraft designers and Navy design monitors to ensure that human factors data had been utilized and applied to the design of aircraft in order to improve the maintainability of their subsystems. When properly used, this check list was also designed to indicate potential design deficiencies during initial development stages relative to maintenance personnel being able to perform maintenance tasks more efficiently and effectively. Timely use of human factor engineering data, it was concluded, allows for engineering changes to be more easily made.

A method of predicting and demonstrating the system effectiveness parameters of combined man-machine systems was developed by the Navy. The Human Reliability Prediction System User's Manual (1977)[20] was developed to predict such parameters as system mission reliability and availability, and design oriented measures such as human and equipment mean-time-between-failure (MTBF). Simple *log-normal prediction models used to estimate maintainability* parameters are presented in the user's manual. These include:

- Maintenance power (repair time as a function of manhours and experience)
- Distribution of repair time per repair, a function of average repair crew experience
- Distribution of man-hours per repair as a function of average repair crew experience
- Number of repairmen per repair

[20] Human Reliability Prediction System User's Manual. Department of the Navy, Sea Systems Command, December 1977.

- Repair crew experience

- Annual man-hours

- Average number of repairmen appearing within each experience category.

Another technique which can be used in the application of maintenance HRD is using correlational models to express the interrelationship of subsystem design, maintenance skill requirements, and resulting job performance. (Eckstrand, 1972)[21] The use of such correlational models would make it possible to predict the impact of alternative equipment designs on training requirements. As a result tradeoffs could be made to determine the best balance between hardware capabilities and maintenance support. A variety of questionnaires, checklists and rating scales can be developed to obtain information concerning system maintenance and skills of personnel.

These correlational models help determine how aptitude, technical training, and subsystem design influence maintenance performance. This information can be used by engineers to adjust the skill levels required of maintenance personnel to obtain optimal output in terms of maintenance time and system reliability. If the required skill levels are considered unrealistic or unacceptable, the engineer can adjust his design accordingly. This methodology can prove useful in improving the quality of input data in simulation models by giving the model a capability of dealing with skill level.

The use of computer simulation models may prove useful in estimating maintenance manpower requirements. Computer simulations can be used to simulate break downs, repairs, and manpower utilization enabling system engineers to consider HRD impacts and alternatives before the system is designed and developed. Maintenance Manpower Modeling (MMM) is a model which has to be used to estimate maintenance manpower requirements for new systems and evaluate the effects of certain system-level tradeoffs. This model has been successfully applied to several different aircraft systems providing early estimates of maintenance task data. Comparability analyses serve to examine maintenance requirements of comparable subsystems and

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[21] Eckstrand, op. cit.

equipment on existing aircraft. A flow diagram for the MMM is shown in Figure 3-1 (Goclowski et al, 1978).[22]

The data obtained through the comparability analysis are combined with a detailed operations scenario and support concept assumptions leading to the development of a simulation program. The Logistics Composite Model (LCOM) simulates the maintenance requirements of the new weapon system providing such information as time span between maintenance actions, task sequencing, task time, maintenance crew sizes and composition, etc.

A problem arising from the use of comparability analysis is the lack of reliability among source data. Tetmeyer et al. (1976)[23] in a report to the Air Force Human Resources Laboratory found that consistent and significant differences between data on the same aircraft and for the same equipment installed in different aircraft resulted in the use of unreliable input data causing reduced output reliability.

The use of factor analytic methods to derive tests which measure maintainability has proven to have predictive validity. Topmiller (1964)[24] investigated the predictive validity of human engineering recommendations included in maintainability design guides. A checklist was developed for each subsystem design feature of selected Air Force weapon systems. The checklist presented choices among alternatives ranging from "The feature is clearly a design characteristic of the equipment" to "The feature is not possessed by the equipment." The data derived from scoring the checklist was compared with mean maintenance times derived from standard Air Force maintenance data reports to evaluate its predictive validity.

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22 John C. Goclowski, Gerard F. King, Paul G. Ronco, and William B. Askren, Integration and Application of Human Resource Technologies in Weapon System Design: Coordination of Five Human Resource Technologies, AFHRL-TR-78-6(1). Air Force Human Resources Laboratory: March 1978. (See also, AFHRL-TR-78-6 (111), May 1978)

23 Cf. Goclowski, op. cit.

24 D.A. Topmiller, A Factor Analytic Approach to Human Engineering Analysis and Prediction of System Maintainability, Report No. AFRL-TR-64-115. Aerospace Medical Research Labs., WPAFB, Ohio: December 1964.

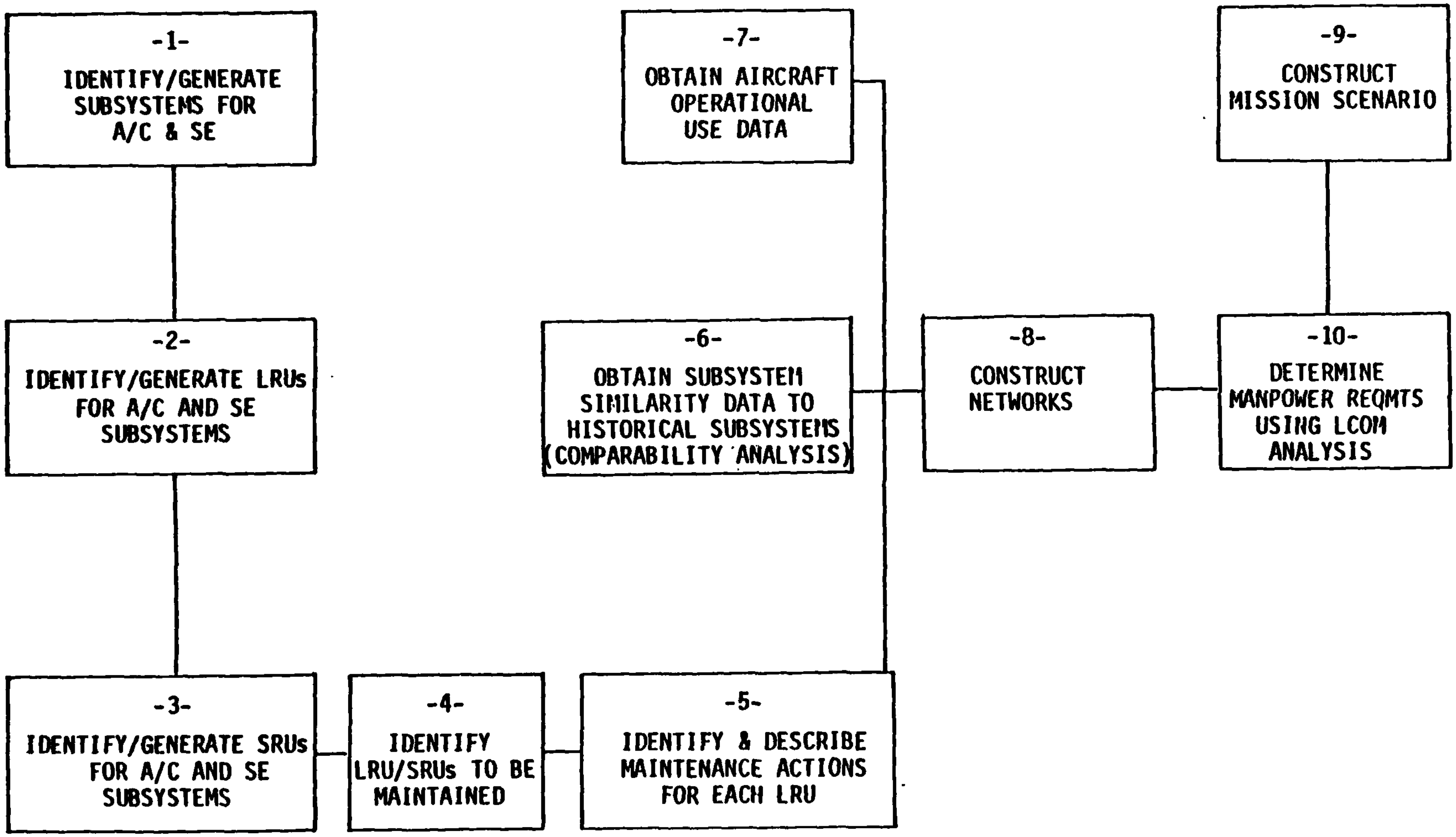

FIGURE 3-1. MAINTENANCE MANPOWER MODELING FLOW DIAGRAM.

Seven factors were identified which significantly correlated with the maintainability criterion. These factors formed seven subtests which include maintenance safety, maintenance information, fasteners and tools, alignment and keying, manual control layout, workspace configuration, and accessibility. These subtests can be used by human engineers to project maintenance manpower requirements and to indicate the extent to which a particular design will meet maintainability requirements.

3.5 TRAINING

The application of HRD during system development to influence the early projection of training requirements can be accomplished by considering five areas of training. These include:

- System trained personnel requirements
- Training plan
- Training equipment development
- Training facilities
- Training support data.

The Instructional System Development (ISD) model is designed for the development and accomplishment of education and training programs in the military.[25] The ISD decision process is shown in Figure 3-2 (Goclowski et al, 1978).[26]

ISD is used to design new instructional systems and improve upon existing systems. A task analysis is conducted to determine if new training programs are necessary and what type of courses are required to administer training. A basic objective of ISD is to facilitate and encourage interservice training in all those situations which meet the established criteria. They are designed to eliminate the possibility of unnecessary duplication of training programs and to take advantage of prior work done in developing training courses

25 Headquarters, TRADOC, Interservice Procedures for Instructional Systems Development, TRADOC Pamphlet 350-30. Fort Monroe, VA: August 1975. (5 volumes)

26 Goclowski, *op. cit.*

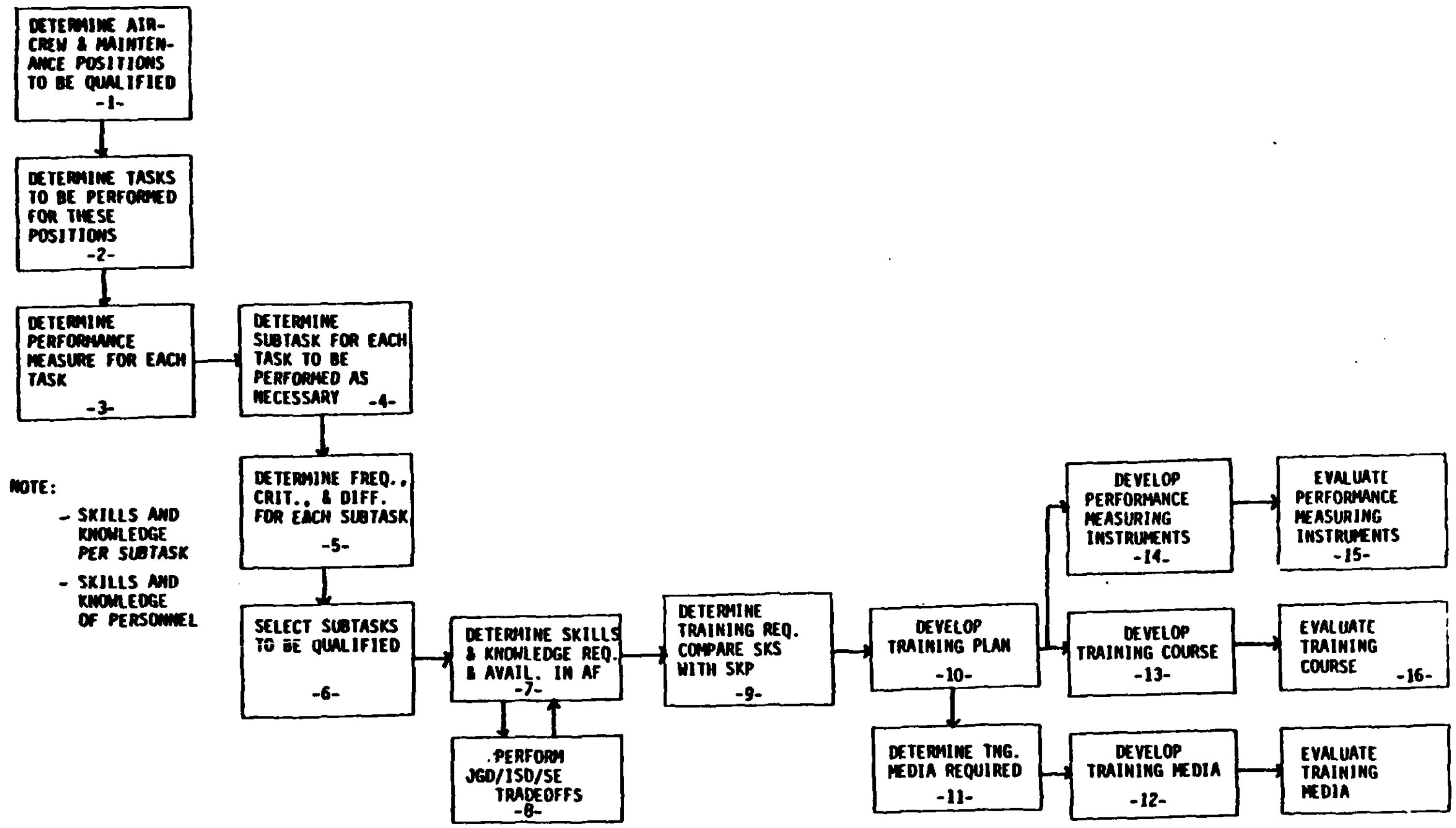

FIGURE 3-2. INSTRUCTIONAL SYSTEM DEVELOPMENT FLOW DIAGRAM.

within the services. This is a useful method of developing inputs to training requirements during system development. The human engineer can be presented information in the form of existing job analysis surveys and, if these sources are similar to those tasks for which current training needs exist, an assessment of HRD training requirements can be made. Trade-off studies on different system designs can assist in making decisions regarding the acquisition of systems requiring the development of new training plans, equipment, and additional training facilities. Projections can also be made of system trained personnel and training support requirements.

The problem with using the ISD model for training development is that the ISD processes do not reach maximum levels of activity until well into the full-scale development phase, when operational and maintenance tasks can be fully defined. This delay can result in the need to restructure training courses which may in turn delay providing the trained operator and maintenance personnel.

A discussion of early training estimation procedures within military system development is provided by Jorgensen (1979).[27] Early training estimations must consider mission requirements based on perceived enemy threat, hardware configurations designed to counter threats, and human resource requirements for operation and maintenance. The approach must flow from the need to meet the performance objectives of the system generated by threat and mission. Figure 3-3 (Jorgensen, 1979)[28] shows the areas of early system development effecting training estimation. Jorgensen reviews important research pertaining to the methodological development of early training estimation procedures.

One of the research areas examined relevant to HRD considerations is task specification. The Systems Analysis of Training (SAT) is one of the few efforts to develop a logical framework to systematically generate a training program for a weapon system in the early stages of development (Jorgensen, 1979).[29] Figure 3-4 shows an example of the behavioral objective format taken from SAT reports. The SAT approach was used by the Air Force to group task

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[27] Charles C. Jorgensen, Early Training Assessment Within Developing System Concepts. US Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA: July 1979.

[28] Ibid.

[29] Ibid.

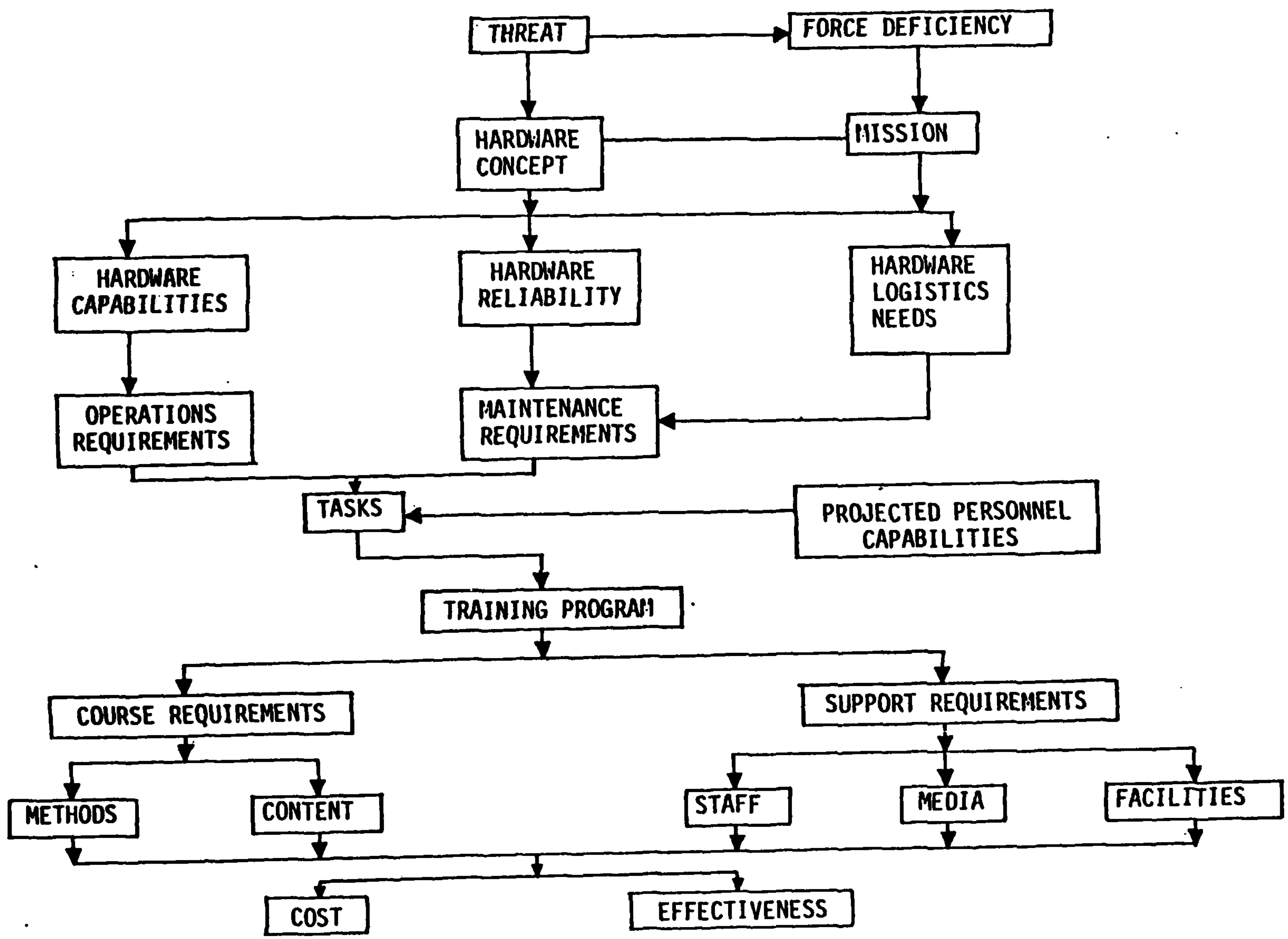

FIGURE 3-3. IMPACTS OF EARLY DEVELOPMENT AREAS EFFECTING TRAINING.

OBJECTIVE: Title of Objective

INITIAL CONDITIONS: State of the Air Vehicle (e.g., Climbing at 2000 ft./min., Electrical Power Available, Etc.)

CONCURRENT BEHAVIORS: Overt of Covert Behaviors Conducted Simultaneously with the Objective Behaviors (e.g., Maintain Constant Heading Through Maneuver)

BEHAVIORS:

INITIATION CUE					COMPLETION CUE		
CONTROL/DISPLAY	RELATION	VALUE	ACTION VERB	CONTROL ON DISPLAY	CONTROL/DISPLAY	RELATION	VALUE

PERFORMANCE: Criteria for Demonstrating Proficiency

ENABLING OBJECTIVE: Skills and Knowledges Necessary to Enable the Trainee to Perform the Behavioral Objective Within the Specified Performance Limits

Skills and Knowledges Necessary to Handle Abnormal Events

Who is Performing the Behavior

INTENTIONS: Crew Coordination

TASK ELEMENTS: Task Elements Incorporated by the Objectice

OBJECTIVE CRITICALITY: On a Three-Point Scale

OBJECTIVE DIFFICULTY: On a Three-Point Scale

FIGURE 3-4. BEHAVIORAL OBJECTIVE FORMAT TAKEN FROM SAT REPORTS.

elements into processing blocks on the basis of common behavioral objectives. Task element data is categorized in groups according to required skills or knowledges. Skills and knowledges are then grouped into behavioral objectives on the basis of categorical commonalities to identify training requirements.

Research studies which examine the effectiveness of alternative training techniques are helpful in identifying training methods which use HRD considerations to bring about more efficient and effective training programs. Leibowitz (1967)[30] describes perceptual research relating to image interpretation and discusses implications for interpreter training. Several possible ways an expert image interpreter learns to separate relevant cues when viewing a complex photograph include:

- increase in specificity
- discovery of distinctive features.

Leibowitz believes verbal learning of visual discriminations is unnatural, and suggests that a better method of learning would be to require the interpreter to make visual discriminations in a way that uses all possible combinations of distinctive features.

Bialek (1973)[31] conducted research to provide information to improve Army training programs. This project examined optimal training strategies for men of differing aptitudes. A series of laboratory studies were performed which systematically manipulated learning variables using different training methods for tasks ranging from simple motor skills to the use of abstract concepts and principles. Subjects differed in aptitude as measured by the Armed Forces Qualification Test. It was determined that the use of different training techniques would be beneficial in terms of cost,

30 H. W. Leibowitz, The Human Visual System and Image Interpretation, Research Paper P-319. Institute For Defense Analysis, Arlington, VA: June 1967.

31 Hilton M. Bialek, John E. Taylor, and Robert N. Hauke, Instructional Strategies for Training Men of High and Low Aptitudes, Technical Report 73-10. Human Resources Research Organization, Alexandria, VA: April 1973.

time, and morale for groups varying in aptitude. Lower aptitude trainees learn better when trained with instructional techniques which maximize personnel interaction. Printed programs or text were least effective with low aptitude trainees. High aptitude trainees were capable of learning many tasks by themselves or with little supervision. Training programs for high aptitude trainees should provide necessary latitude and autonomy such as is provided in self-paced learning. Further research is needed to identify effective training techniques if the capabilities of low aptitude personnel are to be maximized.

In order to design systems which make optimal use of available manpower, the human engineer should be aware of the type or skill level of personnel available to man the system. Considering the present educational and technical capabilities of armed forces personnel, human engineers and training developers should work together to design systems within the capability levels of available manpower.

3.6 HUMAN FACTORS TEST AND EVALUATION

A properly designed human factors test and evaluation plan can be useful in improving the quality of design decisions, correcting design deficiencies early, and integrating hardware with the personnel who operate, control and maintain the system.

The purpose of the testing is to determine how the system will perform in the real world. The objectives characteristic of a personnel-oriented test and evaluation program are:

- Evaluate whether the system can be operated maintained and controlled by personnel

- Improve machine compatability

- Develop valid qualitative and quantitative personnel requirements, selection procedures, manning documents, and organizational tables

- Evaluate training programs, equipment, and supporting materials.

Different test and evaluation techniques vary greatly in their fidelity, a variable that largely determines the ability of the

test conditions to match those in the real world. Figure 3-5 (Chapanis and Van Cott, 1972)[32] shows the tradeoffs between fidelity and flexibility of application of various test techniques. An important part of designing a human factors test and evaluation program is deciding which real-world features to incorporate in the test situation. The validity of the test will be largely determined by successfully defining and including critical variables in the test procedure. It is necessary to include all variables which have an important effect on system performance. Care should be taken to make use of equipment, personnel, procedures, environmental conditions, and feedback stimuli which duplicate those appearing in the operational system.

A wide range of test and evaluation techniques exist including:

- Expert opinion--should be used with caution because of their often subjective and biased nature
- Human engineering checklists--useful in the evaluation of early engineering plans, but with limited usefulness in the evaluation of man/machine interaction
- Mockups--constructed to evaluate equipments or systems before they are actually constructed
- Experimental design--used to describe and measure relationships between operator performance and machine or system variables
- Simulation--used to evalute and demonstrate the application of specific procedures and equipment to specific operations.

From a human engineering point of view simulation techniques have many advantages over other test and evaluation procedures. Simulators can be instrumented to collect data that would be difficult to obtain from real systems, can be easily manipulated and used to

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[32] Chapanis and Van Cott, _op_. _cit_.

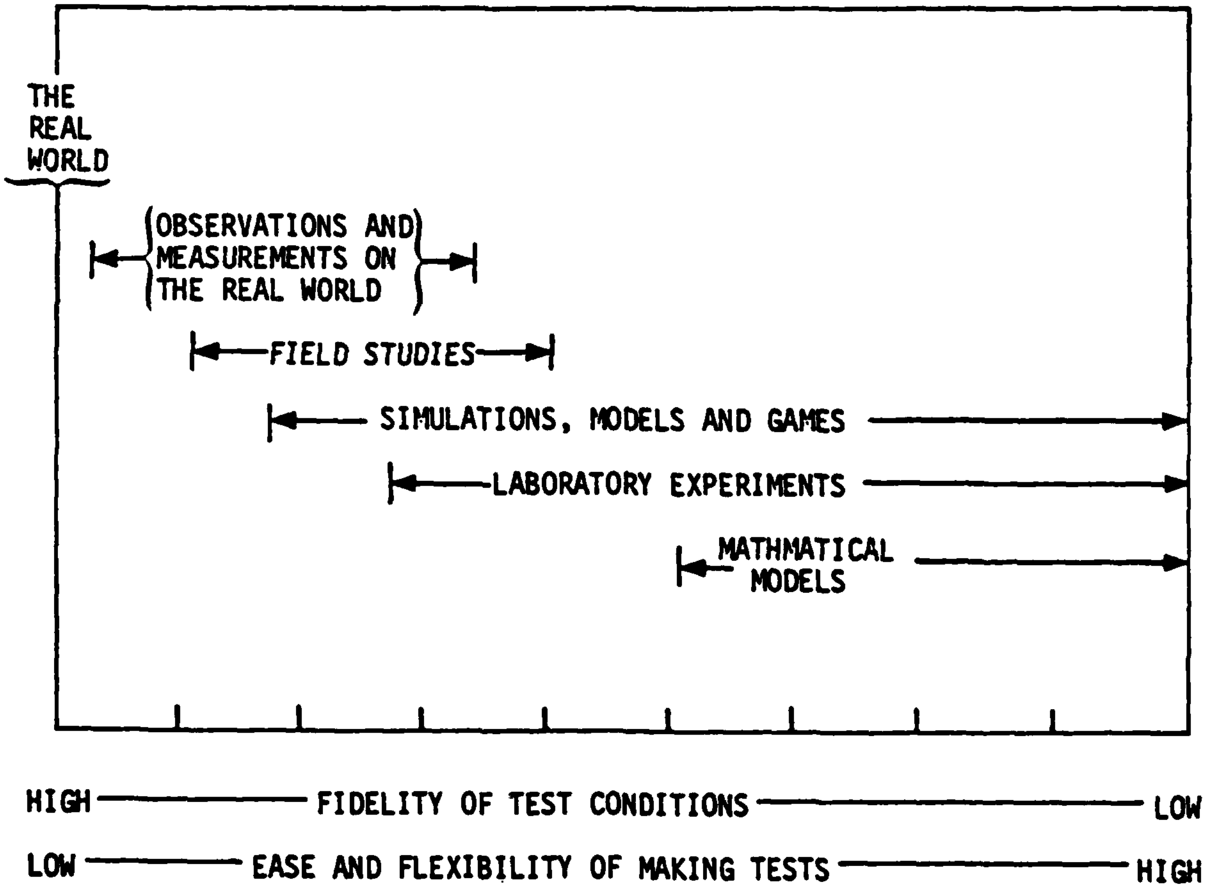

FIGURE 3-5. THE FIDELITY OF VARIOUS TEST TECHNIQUES AND THE FLEXIBILITY WITH WHICH THEY MAY BE APPLIED.

study processes that cannot be studied in real systems (i.e., crashes and accidents), and, most importantly, simulators can be used to study systems and processes which have not yet been constructed or put into operation.

Rupe (1963)[33] conducted a study to develop procedures for building a personnel support system for use during weapon system development. The objectives of the test and evaluation program for new and modified systems should include test and evaluation of the personnel support functions. Various aspects of human factors must be investigated including:

- Man-machine compatibility
- Human factors engineering design
- Personal and protective equipment
- Physiological factors
- Qualitative and quantitative personnel requirements
- Training and training equipment requirements
- Manning and organizational requirements.

Rupe states the primary objectives of the personnel support system test plan as being:

- Determine whether the system is capable of being operated, controlled, and maintained by Army personnel programmed for the system
- Determine whether personnel performance is adequately supported by the proposed, planned, or established equipment design, technical data, job environment, training, organizational control procedures, personnel selection, manning, etc.
- Identify problem areas and deficiencies that can degrade system effectiveness, so that timely corrective action can be taken.[34]

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33 J.C. Rupe, The Production of Training Requirements for Future Weapons Systems: A Personnel Support System Research and Development Process, TR-83. Human Resources Research Organization, Alexandria, VA: April 1963.

34 Ibid., p. 76.

Various methods which can be used in the system test plan include checklists, evaluation guides, task analyses, laboratory experiments, questionnaires, interviews, ratings, and paper-and-pencil tests. Rupe describes the test and evaluation process as follows:

> "All performances required of personnel in the system will be observed and evaluated. Troubleshooting tasks may be tested whenever malfunctions occur during the hardware test program, or by introducing malfunctions in selected critical areas. When any deviation or difficulty is observed or reported, the test team investigates the problem and takes corrective action."
>
> "When test priorities arise, critical operations are given first priority for data collection purposes. For the most part, the operational and technical requirements of the system, including the operational and maintenance concepts, are used as criteria against which to assess the adequacy of the personnel support system processes and products. The test program should progress *from subsystem testing to system testing, and*, ultimately, to evaluations of human performance in the operationally configured system during simulated mission accomplishment."

A report for HEL (1976) serves as a guide for obtaining and analyzing human performance data in a materiel development project. This report gives details showing how tests should be conducted to ensure the effective use of HFE data in the Army's materiel acquisition cycle. Human factors test data are used to identify causes of human error and are used to assess system reliability and effectiveness. The HFE test report analyzes human performance in terms of performance times and error rates and provides qualitative descriptions of factors contributing to error rates and slow performance times. The HFE test report should describe factors that produce errors and suggest ways these problems can be corrected.

The nature of the HFE testing will vary according to the stage of system development--earlier phases focus on functional allocation, workspace design, criticality of equipment components, etc.; whereas later stages assess the operator's ability to perform

his assigned tasks. Testing during the later stages of system development is useful to determine what trade-offs will be made to improve human reliability. At this time tests are necessary to determine the adequacy of personnel selection and training. It is important to select and screen all test participants so that they will closely resemble the eventual system personnel. Training tests should be administered to determine whether refresher training is necessary to sufficiently prepare operators to operate or maintain the system properly. With proper design and implementation, testing will serve to identify the sources of human error and provide solutions for eliminating these areas as early as possible in the system development process.

3.7 SYSTEM INTEGRATION

A process of designing systems is needed which integrates all human resource technologies so that human components are effectively utilized at all stages of system development. Manpower, biomedical, maintenance, and training HRD elements must be coordinated at the earliest time possible in the system development process in the unification of the total system environment including hardware, software, and personnel.

Prerequisite to the development of an integrated HRD technology is a thorough systems analysis. The systems analysis provides the necessary information serving as input to the development of a methodology which systematically applies HRD to all areas of system design. As an effort to integrate all available HRD technologies Goclowski et al. (1978)[35] conducted a research project for the Air Force Human Resources Laboratory. This research examined five human resource technologies in an effort to produce one Coordinated Human Resource Technology (CHRT) which, when applied, quantifies reliability, maintainability, manpower, training, and job guide documentation requirements for a weapon system. This data would allow these factors to influence the design, maintenance, operations, and support concepts in early weapon system acquisition. Table 3-5 (Goclowski et al., 1978)[36] provides a listing of five HRD technologies

35 John C. Goclowski, Gerard F. King, Paul G. Ronco, and William B. Askren, Integrating and Application of Human Resource Technologies in Weapon System Design: Coordination of Five Human Resource Technologies, TR-78-6 (1). Air Force Human Resources Laboratory: 1978.

36 Ibid.

TABLE 3-5
HUMAN RESOURCE TECHNOLOGY DATA

DATA ITEM	HRDT	MMM	JGD	ISD	SOC
1. Viable Design Alternatives	X				
2. Other Alternatives	X				
a. Training	X		X	X	
b. Manuals	X		X	X	X
c. SE	X	X	X	X	X
d. Maintenance	X	X	X	X	X
e. Operations	X			X	X
3. Support Goals					
a. Reliability		X			
b. MMH/FH		X	X	X	X
c. Availability		X			
d. UDL		X	X	X	X
e. Spares		X	X	X	X
4. Unit Cost Goals					X
5. Design-to-Cost Goals					X
6. RIW Considerations					X
7. Multi-National Considerations	X				
8. Annual Flying Hours		X			X
9. Number of Bases		X		X	X
10. Number of Aircraft		X		X	X
11. Crews per Aircraft	X	X	X	X	X
12. Crewmen per Crew	X	X	X	X	X
13. Crew Makeup	X	X	X	X	X
14. Missions		X		X	
15. Mission Essential Elements	X				
16. Performance	X	X			
17. Configuration	X	X	X	X	X
18. Construction	X	X	X	X	X
19. Expected Operational Life		X			X
20. Maintenance Probabilities		X	X	X	X
21 Maintenance Times		X	X	X	X
22. Skill Category		X	X	X	X
23. Skill Level		X	X	X	X
24. Crew Size		X	X	X	X
25. SE Utilization		X	X	X	X
26. Safety Hazards	X	X	X	X	

Legend:
HRDT - Human Resources in Design Trade-Offs
MMM - Maintenance Manpower Modeling
JGD - Job Guide Development
ISD - Instructional System Development
SOC - System Ownership Costing

TABLE 3-5 (Cont.)
HUMAN RESOURCE TECHNOLOGY DATA

DATA ITEM	HRDT	MMM	JGD	ISD	SOC
27. Available Personnel					
a. Years of Service				X	X
b. Labor Rate					X
c. Scores			X	X	
d. Retention Rate			X	X	
e. Predictions			X	X	
28. Task Frequency			X	X	
29. Task Criticality			X	X	
30. Task Difficulty			X	X	
31. Degree of Proceduralization			X	X	
32. Content of Task Information			X	X	
33. Job Guide Concept			X	X	
34. Job Guide Status			X		
35. Manual Content			X		
36. Training Concept			X	X	
37. Training Status				X	
38. Course Content				X	
39. Time to Train				X	
40. Quantity to Train				X	X
41. Training Resources				X	X
42. Cost					
a. SE Investment			X		X
b. Manual Investment					X
c. LRU Spares Investment					X
d. Aircrew					X
e. Fuel					X
f. Depot Repairs					X
g. Facilities					X
h. Inventory					X
i. Technical Record Data					X
j. On/Off Equipment Maintenance					X
k. Training				X	X
l. Maintenance Material					X

Legend:
HRDT - Human Resources in Design Trade-Offs
MMM - Maintenance Manpower Modeling
JGD - Job Guide Development
ISD - Instructional System Development
SOC - System Ownership Costing

and their relative contributions in various data areas. The extensiveness of the HRD item list provides an indication of the comprehensiveness and deployability of this methodology.

The five HRD technologies which are integrated in the CHRT process include Maintenance Manpower Modeling (MMM), Instructional System Development (ISD), Job Guide Development (JGD), System Ownership Costing (SOC), and Human Resources in Design Trade-Offs (HRDT). Integral to the CHRT process are the following activities:

- Development of the consolidated data base (CDB)
- The integrated requirements and task analysis
- Instructional system and job guide development
- The impact analysis.

Goclowski et al. (1978)[37] provides a summary of the CHRT process.

> "The CDB is developed and maintained to service the CHRT methodology. The CDB data is then used for an integrated requirements analysis which quantifies operations, maintenance, and task requirements in terms of reliability (R), maintainability (M), manpower, and scope and magnitude of the instructional system and job guide development effort. These factors together with associated cost data for any specific design are then provided to the user through the impact analysis. CHRT may be reiterated to evaluate various design and support approaches. A traditional but integrated task analysis is performed during full scale development. The instructional system and job guide products are derived from this task analysis."

The use of integrated HRD technologies such as the one described will result in payoffs which manifest themselves in the total performance of the fielded system. In developing a system which applies manpower, biomedical, maintenance, and training HRD elements

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[37] Ibid.

throughout the system design phases, the following benefits will result (Kidd and Van Cott, 1972):[38]

- Improved performance
- Reduced training costs
- Improved manpower utilization
- Fewer losses from accidents and misuse
- Increase economy of production and maintenance
- Improved user acceptance.

3.8 CONCLUSIONS

Applications of HRD to systems design and development have been discussed in a variety of system areas. A majority of research studies which have used HRD methodologies during system development have reached the following conclusions:

- Human factors engineering or human resources data can play a critical role in the overall development of systems.
- Timely use of HRD is important to the design and development of effective systems, i.e., the more and the sooner, the better.
- Successful use of HRD depends a great deal on priorities attached to the man-machine interface and to the availability of technically competent human factors specialists.
- Effective guides, handbooks, and check lists have been developed and tested for increasing the use of HRD in system design and development processes.

In addition, it was determined that the application of an integrated HRD technology is an effective means of considering all HRD elements so that human components are efficiently utilized at all

[38] Kidd and Van Cott, op. cit.

stages of system development. This involves the building of HRD data bases in all system areas and presenting the information in an organized framework which would render it useful for human engineers and system designers. A recapitulation of the HRD methodologies which have been discussed is presented in the following section.

3.8.1 Available Methodologies

Table 3-6 summarizes all HRD system elements discussed in this section and indicates the tradeoff considerations and HRD methodologies which have been discussed for each element.

3.8.2 Technological Deficiencies

Among the HRD methodologies which appear to be weak or in need of further refinement for purposes of system development are those methods in the biomedical and training areas. As discussed in a previous section, experimental methods which are designed to examine the effect of environmental stressors are confronted with the problem of using human subjects. There is still a great deal that is not understood about the complex relationships among stressors which hampers the consideration of such variables in system design.

Applying HRD methodologies in early design phases is necessary and important to the develoment of effective systems. A variety of methods have been discussed which use HRD in system trade-offs, but few are geared to the early phases of development when system specifications are lacking or incomplete. Many methods of applying HRD to training development are not utilized until well into the full-scale development phases when their efficacy is reduced.

New training methods need to be developed which are geared to the capability levels of the personnel available to man the system. Equipment must be designed such that early hardware descriptions leads to the eventual identification of tasks and associated learning objectives. This requires communication between the training analyst and hardware designer in a common language which both parties can understand. Several such research efforts used to improve design communication include the development of a simulation language called ECSL (Extended Continuous Simulation Language), the creation of CAPS (Computer Aided Programming System), and Thoughtsticker--a computer regulated concept interrogation and recording device which forces the

TABLE 3-6. AVAILABLE HRD METHODOLOGIES

HRD SYSTEM ELEMENT	HRD TRADEOFFS	HRD METHODOLOGY
• Manpower and Personnel Requirements	• Numbers • Skill Types • Skill Levels	• System, Job, and Task Analysis • HRD Handbooks
• Biomedical Support	• Environmental - equipment and environmental design impacting on personnel health and safety	• Human Engineering Analysis and Guides - to design for physiological safety and psychological health.
• Maintenance Requirements	• Numbers • Skill Levels • Equipment Design	• Maintenance Manpower Modeling • Comparability Analysis and Correlational Models - to determine maintenance requirements of comparable subsystems • Simulation • Factor Analysis - to derive tests which measure maintainability
• Training Requirements	• Numbers • Training Plan • Training Facilities • Training Equipment • Training Support	• Job and Task Analysis • ISD Process • SAI Process
• Human Factors Test and Evaluation	• Fidelity • Ease of Administration	• Expert Opinion • Equipment Drawings and Diagrams • Mockups • Experimental Design • Simulation to determine how the system will perform in the operational environment
• System Integration	• Manpower Tequirements • Biomedical Support • System Maintainability • Training Requirements • System Reliability	• CHRT Process • Consolidated Data Base • Impact Analysis • Integrated Task Analysis to effectively utilize human components at all stages of system development

consideration of alternative designs. Jorgensen (1979)[39] assesses the future research needs in this area as follows:

> "Thoughtsticker is used primarily in the context of electrical engineering--research is needed to produce a military oriented system. Research must consider the relationships between hardware configurations and their impact on task structure."

In human factors testing as in all forms of testing, tradeoffs must be made in effecting programs which are cost effective and easy to administer while at the same time achieving validity. With the use of improved HRD technologies and carefully designed test and evaluation plans, the "trial and error" method of designing and developing systems will be a thing of the past.

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[39] Charles C. Jorgensen, op. cit.

SECTION IV

SUMMARY AND RECOMMENDATIONS

4.1 EFFECTIVE USE OF HRD IN SYSTEMS DEVELOPMENT

Because of enormous complexities involved in major system acquisiton, Army managers are faced with a wide range of demands on their attention and resources. Priorities must be established to rationally cope with these demands. The assignment of priorities will significantly influence, if not characterize, system development.

As a general rule, the degree of success achieved in addressing human resources issues is directly proportional to the degree of management emphasis; and the longer the delay in applying this emphasis, the greater the cost to address the issues. All three US Army system developments examined in this study confirm this conclusion.

SOTAS is an example of high management priority for human resource issues from the very beginning of the program. Although the SOTAS concept implies some inherently difficult personnel and training problems, the early attention given these difficulties has allowed the Army to overcome their adverse impacts. Further, SOTAS is the only major Army system known to the study team in which the training devices were developed in true sychronization with the end item.

The focal point for addressing human resource issues in SOTAS was the Deputy Project Manager (DPM), assisted by a team of behavioral scientists under contract to the PMO and independent of the hardware contractor. That the prime advocates for the behavioral point of view had direct access to key PMO management personnel appears to be very significant.

In the TOS program, on the other hand, human resource issues were assigned a low priority relative to other problems considered to be more pressing. In interviews conducted by the study team the PMO staff clearly expressed their primary concern for software engineering problems. They described human resources issues as one of "the ilities" (such as maintainability or nuclear hardening), a term indicating issues peripheral to the central thrust of system development.

Over its long history the TOS materiel development team has had no focal point for the address of human resource issues. This may explain why behavioralists have had such a small impact on system development, in spite of the considerable amount of work which was done on TOS-related projects. Personnel and training requirements are still largely undefined and untested. There appears to be considerable room for improvement in the human factors engineering aspects of end item hardware and software.

XM1 has had variable degrees of emphasis on human resource issues. The system may be divided into four major areas: operation, organizational maintenance, DS/GS maintenance, and logistic support. Management interest in operation was intense since program inception (Main Battle Tank Task Force Report, 1972); the other three areas began to receive major management attention at progressively later dates: organizational maintenance after DT/OT I (1976), DS/GS maintenance after DT/OT II (1978), and logistic support at ASARC III (1979). Degree of success in addressing human resources issues appears in corresponding order, with a high degree of success in operation (e.g. crew size and end item HFE), less in organizational maintenance (e.g. AMMH), still less for DS/GS maintenance (e.g. requirement for a turbine engine repairman), with many significant problems outstanding for logistic support (e.g. manning levels).

HFE efforts in XM1 were generally assigned to the hardware contractor. Human factors aspects of the end item were of particular interest to key Army executives. Several times in the program improvements in the tank's HFE resulted from inspections by general officers.

In all three systems there is a correlation between early application of behavioral expertise and success in addressing human resources issues. The study team concludes that behavioral experts should be an integral part of the system design effort. Whether these experts work directly for the system PM, for a contractor, or for an independent agency does not appear to be significant. What does appear to be significant is the degree to which their voices are heard by the PM.

It is of interest to note that none of the military personnel assigned to the project management offices or the requirements development offices were trained in human factors or other behavioral areas. Nor does there appear to be a program to develop officers with such technical training, although training in other technical areas

(such as engineering) is commonplace. Military personnel with a strong behavioral background would be ideally suited to translate between military managers and human resource researchers. This could result in a better focusing of behavioral work in materiel development, as well as increased credibility for human resource demands.

4.2 GENERATION OF CRITICAL HRD IN SYSTEM DEVELOPMENT

In system development it is a generally accepted practice to conduct subsystem performance tests to generate data to aid hardware/software design and validation, outside of the DT/OT cycle. Examples of this are: SOTAS' 1975 test of the feasibility of closed-loop targeting; TOS' software requirements studies; and XM1's ballistic testing.

The use of testing off-line from the usual DT/OT process is particularly important, since DT/OT is oriented toward management decision making. The pressure for the system to "pass" the test inhibits opportunities for experimental learning.

It is, however, not a generally accepted practice to perform such tests to obtain data specifically on the personnel and training subsystems. SOTAS stands out as a major exception. As early as 1975 PM SOTAS conducted personnel requirements tests that identified key experience requirements for operators. Development and testing of the SOTAS training program was performed continuously and in conjunction with system configuration. It is the study team's opinion that the SOTAS project has demonstrated the feasibility of early analysis and testing of personnel requirements.

Over a period of nearly a quarter of a century TOS underwent many test processes, including field usage in Europe and extense software experimentation at the Combined Arms Center. However, critical personnel and training requirements were not determined by these tests.

A review of the case studies of TOS and SOTAS show that both programs were the object of a considerable amount of behavioral research. It would be difficult to say that the amount of effort applied by Honeywell to SOTAS was significantly more or better than that applied to TOS by BESRL/ARI. Yet, the SOTAS effort appears to be so much more successful. Why?

It appears to the study team that the reason is that the SOTAS work was full integrated with the SOTAS project, while the TOS work was essentially a parallel process. The TOS project personnel do not appear to have been very much involved in the BESRL/ARI work nor very aware of its significance to their project.

4.3 TECHNOLOGICAL GAPS IN HUMAN RESOURCE DATA

Section III discussed the state-of-the-art in HRD, with conclusions on research required in specific technologies. This section discusses technological gaps from the systems acquisition point of view.

4.3.1 Training Requirements

The development of training requirements appears at present to be more of an art than a science. Even the development of an acceptable skills taxonomy--which would seem to be a very basic building block to any scientific approach to training requirements--is apparently beyond the state-of-the-art.[1]

SOTAS, again, appears to be an exceptional system. The SOTAS training program was developed by the PM's team of independent behavioralists from Honeywell Corporation using their SOTAS simulator in conjunction with end item design experiments. The time and expense of such an effort was justified by the complexity of the system and the high skill requirements. While this approach was a brilliant success, it is probably too costly to serve as a model for most systems developments.

The development of training device requirements presented one of XM1's biggest difficulties. The three year delay in the development of TDRs may be intepreted as resulting from a divergence of opinion on the requirement for fidelity in the training devices. While the argument was finally settled, it does not appear to have been upon the basis of any empirical evidence.

[1] Cf.,e.g., J.M. Levine, D. Schulman, R.E. Brahlek, and E. Fleishman, Trainability of Abilities, Tech. Rep. 80-3. Advanced Research Resources Organization, Washington, D.C.: April 1980.

It is the opinion of the study team that there is a serious lack of empirical evidence and validated scientific theory to support rational, convincing decisions on training requirements. This is particularly the case for determining fidelity requirements for training simulators. The need to determine simulator fidelity requirements is especially critical, since technology and the cost of such devices appears to be increasing faster than the experience base.

4.3.2 Personnel Skill Requirements

Closely related to determining training requirements is determining personnel skill requirements. There are two aspects to this problem:

(1) Designing equipment to meet personnel skill restraints

(2) Selecting personnel to meet skill requirements of given equipment.

SOTAS, TOS, and XM1 all experienced disappointments in the first area. Hopes to use relatively junior enlisted personnel as SOTAS operators gave way during personnel testing early in the program. TOS personnel performance problems during FM 222 are still not complete solved. The XM1 DT II revealed potential skill problems in organizational maintenance positions.

If the design cannot be made to fit the personnel, then the personnel must be selected to fit the design. The steady increase in equipment sophistication, combined with the Army's increasing difficulty in meeting enlistment quotas only accentuates an already formidable problem.

The tools to predict the success of personnel at specific tasks based on aptitude testing are still in a rudimentary state, but a number of efforts have been made. For example, during the M60A1E3 OT II ARI/Fort Knox collected data to determine if gunnery performance could be predicted by psychomotor tests; unfortunately, small sample size limited statistically significant results.[2] The study team believes that additional efforts to relate aptitude testing to task performance could result in significanatly improved usage of scarce personnel resources.

4.3.3 Measuring the Impact of Human Resources on Battle Outcome

As part of the decision-making process the Life Cycle System Management Model (LCSMM) requires an analysis of system operational effectiveness at several points in the development cycle. A Cost and Operational Effectiveness Analysis (COEA) is usually conducted to meet this requirement for major milestones. Other operational effectiveness analyses may be conducted to support the development effort.

Such analyses generally measure the impact of the system on battle outcome in comparison to a baseline system. Typical measures of effectiveness are attrition, survivability, change in force ratio, FEBA movement, and battle duration. The Army has developed numerous models and simulations to support these analyses.

The degree to which these models and simulations incorporate human resources aspects of systems varies according to level and resolution. Some of the high resolution, small unit level simulations (e.g. CARMONETTE[3]) explicitly model operator performance (e.g. time to acquire target, time to engage target forces on system performance).

It does not to appear, however, that human performance was ever played as a variable in the analysis of XM1, TOS, or SOTAS (or in any system known to the study team). That is, some level of human performance was assumed (usually a level at or near the limit of system capability) and fixed among all comparisons.

The number of human resources issues that can be explicitly represented in combat models is relatively small compared to the total range of human resources issues. In particular, no models appear to

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[2] USAOTEA, M60A1E3 Operational Test II (U), OT-014-TEF. Falls Church, VA: April 1975 (CONFIDENTIAL), pp. 80-107.

[3] CARMONETTE was the primary combat model employed in the XM1 COEA by the US Army Concepts Analysis Agency and XM1 COEA Update by the US Army Armor Center.

be available which were specifically designed to address the role of human resources issues as a constitutent part of the combat equation.[4]

4.4 RECOMMENDATIONS FOR FURTHER RESEARCH

To reiterate the initial point of the section, the key to successful addressal of human resources issues is to focus management attention of the problems of human resources as forcefully and as early as possible. In order to do this effectively and consistently, management must be shown the direct relevance of human resources requirements on system effectiveness in a quantitative and credible fashion. The two recommendations presented below constitute a program to establish a quantitative link between human resources and battle outcome.

4.4.1 Human Resources Data Base

At the end of World War II the Army concluded that there were many aspects of firepower that were not understood sufficiently. To remedy this situation an extensive program of ballistic testing was undertaken by AMSAA and the Ballistics Research Laboratory to establish a data base. This data base serves as the empirical underpinning for efforts to model the impact of firepower on combat outcome.

A similar program of research should be undertaken to develop a data base relating human aptitudes and basic skills to task performance, training requirements, and personnel requirements. The establishment of such an empirical basis would significantly advance the state-of-the-art in personnel and training subsystem design and also enhance the credibility of the human resources community in the systems acquisition process.

The development of such a data base will take many years. As the process unfolds a series of handbooks should be written (and

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[4] Under contract to ARI (Contract No. MDA903-78-C-2030) SAI has developed a concept for a division-level battle simulation which specifically models human performance of the division staff. To the study team's knowledge this is the only detailed design of a battle simulation intended explicitly for the examination of human resource issues. See R.V. Tiede, R.A. Burt, and T.T. Bean, Design of an Integrated Division-Level Battle Simulation for Research, Development, and Training, VOL I, ARI Technical Report TR420, March 1980.

frequently updated) summarizing the available data. Four specific areas should be emphasized:

- Design-to-capabilities
- Personnel requirements
- Training device fidelity
- Training requirements.

Additional areas should be added as appropriate.

"Design-to-capabilities" handbooks would be addressed to the hardware developer to assist him in producing an end item which can be operated and maintained by the type of personnel who will actually be available to man the system. They would also be useful in helping to identify impossible requirements early in the development cycle. Such handbooks would supplement traditional human factors engineering guides by considering a broader range of questions than HFE guides generally do.

Personnel requirements handbooks would address a problem complementary to that addressed by "design-to-capabilities' handbooks: given tasks and hardware, how can personnel be selected to man the equipment. While it is always more desirable to handle personnel requirements through the "design-to-capabilities" approach, it is advisable to be well prepared for cases where that is not possible.

Recent and projected advances in training device technology and corresponding increases in cost have made training device cost-effectiveness an increasingly important factor in system development. While it seems clear that high fidelity devices can provide effective training, it is not clear in what cases lower fidelity, lower cost devices are equally effective. Since critical decisions on fidelity must be made in the concept design stage, it is important to have as broad a data base as possible to make rational, defensible decisions.

Training developers are under increasing pressure to cut training resources to decrease costs. A quantitative estimate of the impact of resource cuts would increase the trainer's ability to argue his position.

4.4.2 Modeling the Impact of Human Performance on Battle Outcome

A program of research should be initiated to establish the capability to model the impact of human performance on battle outcome. Such capability would allow rational trade-offs between human resources and hardware. Several steps need to be undertaken.

First, a survey of currently available combat models needs to be conducted to determine what human performance parameters are incorporated in what models. This would constitute a summary of the state-of-the-art. It would also provide the human resources community with the information they require to provide input to models, thus increasing their impact on system development.

Concurrent with the first step, a list of human performance parameters which ought to be incorporated into combat models should be defined and developed. Where data sources for the parameter values are available, they should be identified. Where data sources are not available, programs for developing sources should be identified (This clearly relates to paragraph 4.4.1). A comparison of the model survey with the list of human performance parameters will show the scope of the problem. It is virtually certain that many gaps will be identified. These gaps need to be prioritized and a remedial program initiated.

4.4.3 Summary of Recommendations

The two recommendations presented are clearly closely related. Taken together they represent a program to quantify the impact of human resources on battle outcome. The first recommendation calls for an empirical data base; the second applies that base to theoretical models.

While the two recommendations can be and are best executed together, either one alone provides important benefits. The existence of a data base will assist training and personnel developers make better informed and more consistent decisions. The existence of a modeling capability, even without an empirical data base, will allow parametric analyses which can define the scope of human resources impacts.

APPENDIX A

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APPENDIX B
ARMY MAJOR SYSTEM ACQUISITION

This section presents an overview of the research, development, and acquisition process by which the Army brings new major systems into the inventory. System acquisition is governed by a large and complex series of guidelines and directives issued by various interested organizations, from the Executive Office of the President down to major Army commands. These guidelines are intended to be both comprehensive and flexible; consequently they contain a wide variety of options and alternatives.

The overview presented here is a "snapshot" of the acquisition cycle as it is presently defined. Conflicts between regulations have generally been resolved on a most-recent-date basis. Only a discussion of major systems is considered herein.

B.1 OFFICE OF MANAGEMENT AND BUDGET GUIDANCE

The Executive Office of the President exercises primary control over the acquisition cycle through the Office of Management and Budget (OMB). Policy guidelines have been promulgated by the Office of Federal Procurement Policy (OFPP) in OMB Circular A-109.[1]

A-109 policy applies to all major federal acquisitions from hospitals and energy demonstrations to defense and space programs. Figure B-1[2] shows the A-109 acquisition cycle. Four key decision points[3] are shown in the figure.

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1 Major Systems Acquisition, OMB Circular A-109. OMB, Washington, D.C.: April 5, 1976. (See also: Major Systems Acquisition: A Discussion of the Application of OMB Circular No. A-109, OFPP Pamphlet No. 1. OFPP, Washington, D.C: August 1976)

2 Source: OPFF Pamphlet No. 1, op. cit., p. 21.

3 A-109 decision points 1, 2, 3 and 4 correspond to the Army's Milestone 0, Milestone I (ASARC/DSARC I), Milestone II (ASARC/DSARC II), and Milestone III (ASARC/DSARC III), respectively.

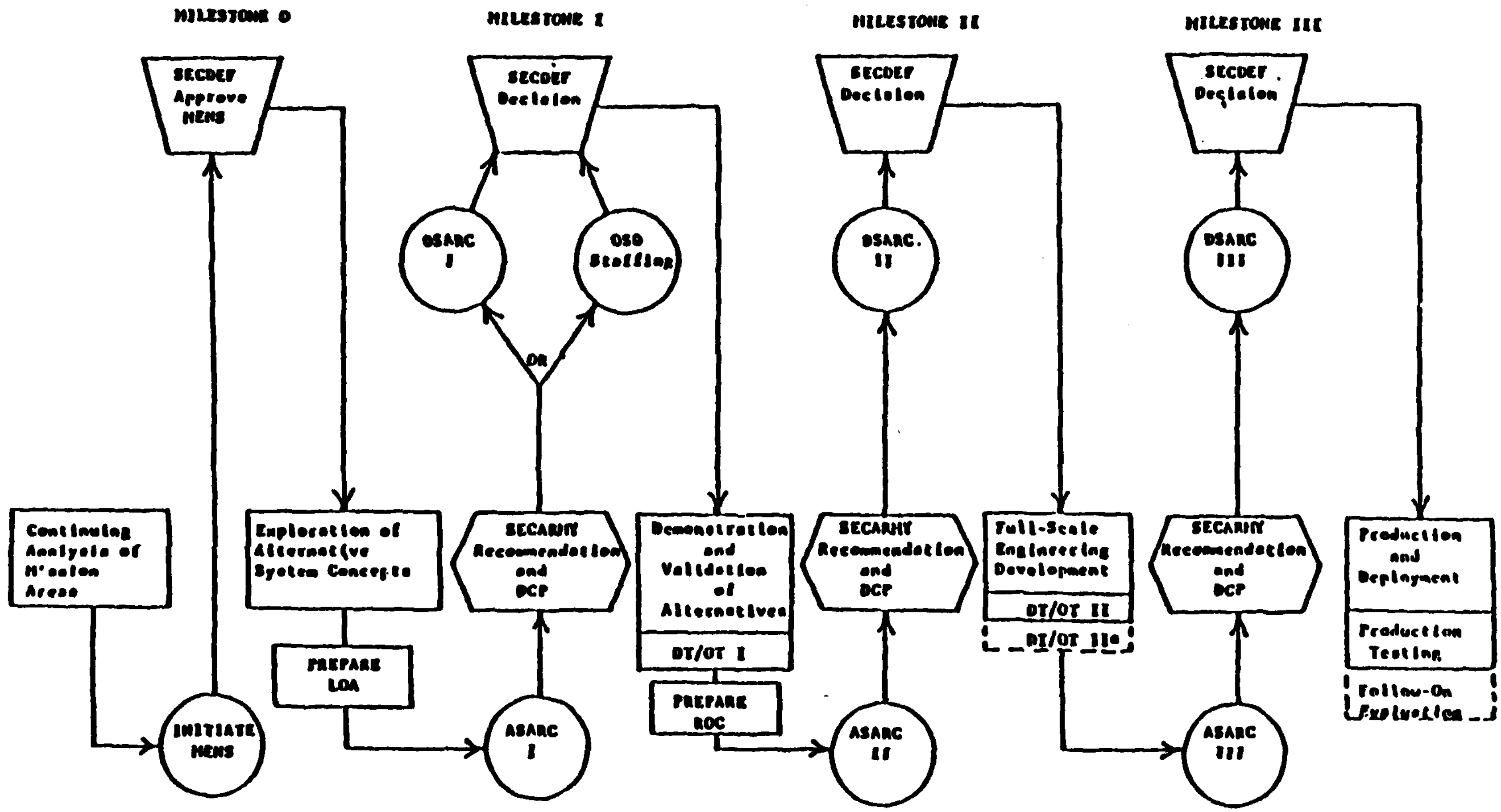

FIGURE B-1. ARMY DEVELOPMENT CYCLE FOR MAJOR SYSTEMS.

At the first key decision point the proponent agency must establish its requirement for the new acquisitionin terms of its mission. This is accomplished through the Mission Need Statements.[4]

This is followed by an exploration of alternative systems to meet the mission need. The second key decision point selects one or more of these alternatives.

The philosophy of A-109 calls for two or more parallel, short-term contracts followed by competitive tests. The third decision point selects a single contractor to proceed with Full Scale Engineering Development (FSED).

After extensive test and evaluation under operational conditions, a production decision is made. This is the fourth key decision point.

The A-109 process is primarily concerned with validating the need for and controlling the expenditure of funds; hence, personnel and training considerations are not explicitly defined therein. However, personnel and training considerations are (or should be) implicit in the analysis of alternative systems, the selection from competitive demonstrations, and the pre-production test and evaluations.

Implementation of the A-109 philosophy has been slow and difficult throughout the government. The Department of Defense (DoD), which has taken the lead, has encountered many problems and new DoD directives are currently being developed to clarify the situation.

B.2 DEPARTMENT OF DEFENSE REGULATIONS

DoD policy and OMB Circular A-109 are implemented through a long list of DoD Directives (DoDDs) and Instructions (DoDIs). The key directives for the acquisition cycle are currently DoDD 5000.1,[5] DoDD 5000.2,[6] and DoDD 5000.30.[7] However, these three directives are

[4] This corresponds to the Army's Mission Element Need Statement (MENS), which should not be confused with the Materiel Need (MN).

[5] DoDD 5000.1, Major System Acquisition. January 18, 1977.

[6] DoDD 5000.2, Major System Acquisition Process. January 18, 1977.

[7] DoDD 5000.30, Defense Acquisition Executive. August 20, 1976.

expected to be soon superseded by a new DoDD 5000.1[8] and DoDI 5000.2,[9] so the discussion herein will address the new documents.

The Office of the Secretary of Defense (OSD) is primarily concerned with four major decision points: approval of the Mission Element Need Statement (MENS) and the Defense System Acquisition Review Councils (DSARCs) I, II, and III. Consequently, DoDD 5000.1 and DoDI 5000.2 are primarily directed at preparing for, executing, and following up actions taken at these decision points.

The key document at Milestone 0 is the MENS. This document is limited to five pages and must consider the mission, threat, need, constraints, and schedule. Manpower considerations are the only part of the constraints related to personnel and training issues.

The key documents for entry into the three DSARCs are the Decision Coordinating Papers (DCPs) and the Integrated Program Summaries (IPSs). The DCP is concerned primarily with funding and schedule. The IPS, however, specifically directs the services to consider manpower and training alternatives as well as provide an overview of the test and evaluation plan.

The IPS is a new requirement and it remains to be seen what, if any, impact it has on human dimension aspects of systems development. It does require consideration of the impact of alternatives on manpower and training, including job-task identification, requirements for training aids and devices, and plans for testing and evaluating manpower and training requirements. The manpower and training sections of the IPS are each limited to two pages.

Recent concern over the long term manpower outlook has caused the Assistant Secretary of Defense (Manpower, Reserve Affairs & Logistics) (ASD(MRA&L)) to require a formal Manpower Analysis Paper (MAP) to support each major milestone.[10, 11] The MAP presents an

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8 DoDD 5000.1, Major System Acquisition (Formal Coordination Draft). October 17, 1979.

9 DoDI 5000.2, Major System Acquisition Procedures (Formal Coordination Draft). October 17, 1979.

10 ASD(MRA&L) Memorandum, Subject: Manpower Analysis Requirements for System Acquisition. August 17, 1978.

11 For an example, see: Manpower Analysis Paper (MAP) III AN/TTC-39 Circuit Switch and AN/TYC-39 Message Switch. U.S. Army Signal Center and Fort Gordon: December 4, 1979.

analysis of the manpower requirements by Military Occupational Specialty (MOS) and skill level for each unit type. It specifies trade-offs among manpower, design, and logistics elements.

B.3 DEPARTMENT OF THE ARMY REGULATIONS

The Department of the Army (DA) implements DoD guidance through Army Regulation (AR) 1000-1[12] and supporting ARs and DA pamphlets and circulars. Additional guidance is provided by supplementary regulations, pamphlets, and circulars issued by subordinate commands.

This paragraph presents a three part overview of the implementation of AR 1000-1. The first part discusses the roles of the key participating commands. The second considers the role of test and evaluation (T&E). The last traces the Army Life Cycle System Management Model (LCSMM).

B.3.1 Major Responsibilities

The Army has divided the responsibilities of the system acquisition cycle into four major areas: The proponent (or user's representative), the materiel developer, the operational tester, and the logistician. Guidance, coordination, and OSD interface is provided by the DA staff.

B.3.1.1 Proponent

The system proponent, or user's representative, is the US Army Training and Doctrine Command (TRADOC). TRADOC's responsibilities are divided between Combat Developments and Training Developments. Each system is assigned to a school or center.[13]

For each major system, a TRADOC System Manager (TSM) is chartered by the Commanding General, TRADOC, to be the focal point for all TRADOC activities and the point of contact for other commands. He tasks TRADOC organizations and ensures compliance with TRADOC requirements.

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[12] AR 1000-1, Basic Policies for Systems Acquisition. April 1, 1978.

[13] TOS is assigned to the Combined Arms Center. SOTAS is assigned to Intelligence Center. XM1 is assigned to the Armor Center.

As combat developer, TRADOC establishes the need and sets the requirements for new systems. It also establishes manpower and personnel requirements.

As training developer, TRADOC designs and executes training programs. It must also review and approve training materiels procured by the materiel developer. TRADOC establishes requirements for training devices and is responsible for certifying that players on operational tests are adequately trained.

B.3.1.2 Materiel Developer

The Materiel Development and Readiness Command (DARCOM) is the Army's materiel developer. For each major system a Project Manager (PM), chartered by the Secretary of the Army and assigned to a commodity command,[14] acts as DARCOM's principal agent. The PM is responsible for developing a total program acquisition strategy. His primary concern is the development of hardware, on time and within funding constraints. Other major responsibilities include the following:

- Logistic support planning
- Preparation of baseline cost estimates in accordance with work breakdown structure
- Preparation of outline development plan, development plan, resident training plan, and new equipment training plan
- Development of independent parametric cost estimates
- Producibility engineering and planning
- Identification of long lead time component requirements
- Initial Qualitative and Quantitative Personnel Requirements Information (QQPRI) and MOS decisions

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14 TOS AND SOTAS are assigned to the Communications-Electronics Command (CECOM). XM1 is assigned to the Tank-Automotive Command (TACOM).

- Contract award for low rate initial production and initial production facilities

- Development of technical manuals

- Coordination with test agencies.

As the focal point for scheduling and funding, the PM is, in practice, the single most powerful voice in the system acquisition cycle.

Because of the increasing complexity and cost of training devices, DARCOM established the PM for Training Devices (PM TRADE) for both system and non-system training devices. PM TRADE is chartered by the Secretary of the Army and reports directly to DARCOM. Originally, PM TRADE was available to any PM who requested assistance. More recently, DARCOM has required that every PM consult with PM TRADE.

PM TRADE is funded by the system PM and there is generally close coordination between the two PM offices. In other respects, PM TRADE's responsibilities for training devices exactly parallel that of the system PM for materiel. PM TRADE responds to the proponent's requirements (through the TSM). He is responsible for developing a training device acquisition strategy within the context of the system acquisition strategy.

B.3.1.3 Operational Tester

The Army's independent agent for operational test and evaluation is the US Army Operational Test and Evaluation Agency (OTEA), an agency of the Office of the Chief of Staff, Army, generally working directly with the Vice Chief of Staff, Army.

OTEA is responsible for planning, managing, and independently evaluating all operational tests (OTs) for all major systems. OTEA will generally assign the conduct of an OT to a TRADOC test agency with players from a field unit.

B.3.1.4 Logistician

The Logistician for the Army acquisition cycle is the US Army Logistics Evaluation Agency (LEA), an agency of the DA Deputy Chief of Staff for Logistics (DCSLOG). LEA's activities are, however, confined almost entirely to review. Logistics requirements are generally set by TRADOC and logistics planning is primarily the responsibility of the PM.

B.3.1.5 Department of the Army Staff

The Army staff provides overall program coordination and integration of the materiel system into Army. The focal point for DA activities for a system is the DA System Coordinator (DASC) in the Office of the Deputy Chief of Staff for Research, Development, and Acquisition (DCSRDA).

The Deputy Chief of Staff for Operations and Plans (DCSOPS) is responsible for establishing and validating capability goals, materiel objectives and requirements, overall force structure design, basis of issue plans, and user testing. DCSOPS establishes priorities for materiel requirements, development, affordability determinations, and procurement of equipment. DCSOPS designates programs as major programs and has primary responsibility for supervising Special Task Forces (STFs).

Staff responsibility for reviewing logistic support belongs to DCSLOG. DCSLOG is especially concerned with integrating system logistic support into the total Army system.

The Office of the Deputy Chief of Staff for Personnel (DCSPER) and its agency, the Military Personnel Center (MILPERCEN), have responsibility for developing a personnel system to meet the needs of new or improved doctrine, organization, and materiel including the determination of new or revised MOSs. MILPERCEN also develops the MILPERCEN Initial Recruiting and Training (MIRAT) Plan.

The Army Research Institute for the Behavioral and Social Sciences (ARI) is an agency of DCSPER and is responsible for supervising and conducting behavioral sciences research, including assessment of quantitative and qualitative manpower resources and requirements systems for individual and unit training, and human factors affecting military operations. While ARI is not specifically mandated to participate in any given activity in the acquisition cycle, it frequently provides assistance on a request basis.

B.3.1.6 User

The users are Army field organizations, e.g., the Forces Command (FORSCOM) or US Army, Europe (USAREUR). The user is not an official participant in the acquisition cycle, but is represented by TRADOC. In practice, however, coordination with user units for input and force development testing can be critical in systems development.

B.3.2 Test and Evaluation

B.3.2.1 Types of Test and Evaluation

Developmental test and evaluation (DT&E) is conducted to assist the engineering design and development processes and to verify attainment of technical performance specifications and objectives. As such, it is critical to determining whether or not a system is acceptable for military use. It is accomplished in factory, laboratory, and proving ground environments using experienced and qualified civilian and military personnel. To the maximum extent possible, contractor and government development testing is integrated into one test cycle during the demonstration and validation phase and another during the full-scale engineering development phase of the materiel acquisiton process.

Operational test and evaluation (OT&E) is that test and evaluation conducted to estimate a system's operatonal effectiveness (including military utility, vulnerability, and survivability), and operational suitability (including compatibility, rationalization, standardization, interoperability, reliability, availability, maintainability, logistic supportability, safety, health, human factors, and trainability), as well as the need for any modifications. In addition, OT&E, provides information on organization, personnel requirements, doctrine, and tactics.

Operational test and evaluation is accomplished by units consisting of operational and support personnel for the type and qualifications of those expected to use and maintain the system when deployed, and is conducted in as realistic an operational environment as possible. A realistic operational environment includes tactical operations conducted in accordance with the combat developer's operational mode summary which specifies the number and type of combat operations during a period of time. The environment under which these operations are conducted may include the employment of opposing forces; electronic and other enemy counter-measures; chemical, biological, and radiological warfare; and smoke or other forms of battlefield obscuration. Where appropriate, operations may be conducted in urban training areas. Independent evaluations of operational tests are provided directly to each member of the decision review body.

Force development test and experimentation (FDTE) are tests that are performed to support the force development processes by

examining the impact, potential, effectiveness, and interdependence of selected concepts, tactics, doctrine, organization, and materiel. They support the materiel acquisition process by providing data to assist in the development of requirements, to develop fundamental data necessary for a full understanding of the performance of a materiel system, or to assist in validating doctrine and/or tactics to counter a possible threat response to a system once deployed. FDTE may be used to develop the concept of employment, determine operational feasibility, estimate the potential operational advantage of a proposed system, and assist the combat and materiel developers in the development of requirements documents.

B.3.2.2 An Example of the Test Cycle

The six basic test cycle documents and the process they follow are shown in Figure B-2. These same documents are shown in Figure B-3 with enough elaboration to reflect the OT&E process within a cycle.

The OT&E cycle starts with identification of operational issues (or a revision of them if there was a previous cycle) by proponent commands or agencies. The issues form the basis for initiating (or revising) the Independent Evaluation Plan (IEP). The IEP programs the use of all available data, regardless of source, to evaluate the system's operational effectiveness and suitability. When the IEP is sufficiently developed to identify what data are required from operational tests and operational performance criteria, test concepts are prepared (or revised) for each required OT. The test concept also forms the basis for preparing (or revising) an outline test plan (OTP) for each required operational test.

After the IEP for a phase is approved, the test design plan (TDP) is prepared. The TDP delineates only as much of the test planning as is necessary for the approval authority to be assured that the test will satisfy its objectives, leaving some flexibility in the detailed planning to the test director. Preparation of the TDP requires input from the materiel developer concerning maintenance and new equipment training (NET) and from the combat developer and trainer concerning means of employment, organization, logistical concepts, threat, mission profiles, test environment, and training. The inputs are referred to as the materiel developer test support package (TSP) and the combat developer TSP. When the TDP has been approved a detailed test plan (TP) is prepared and used by the test director.

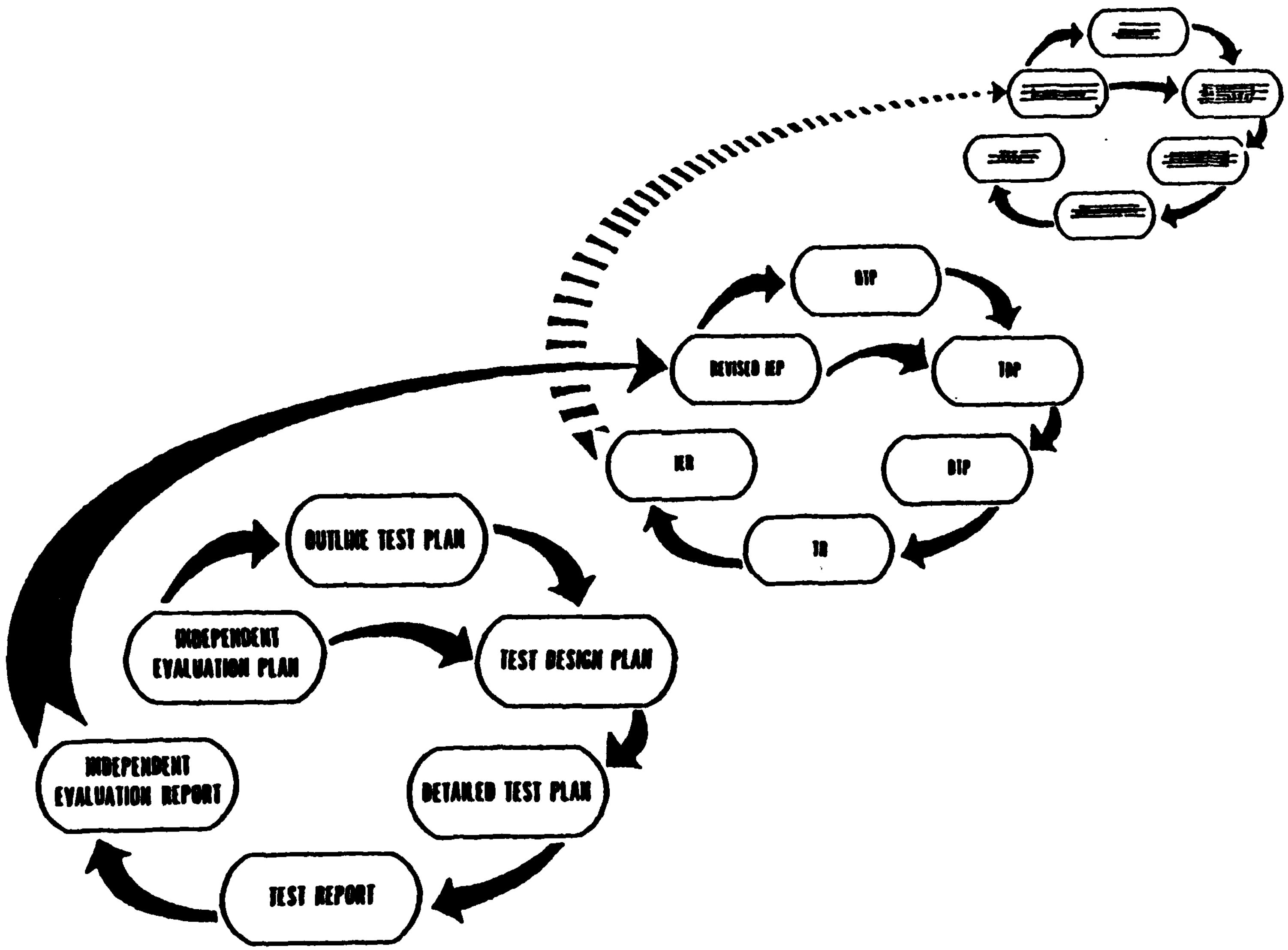

FIGURE B-2. OPERATIONAL TEST AND EVALUATION CYCLE

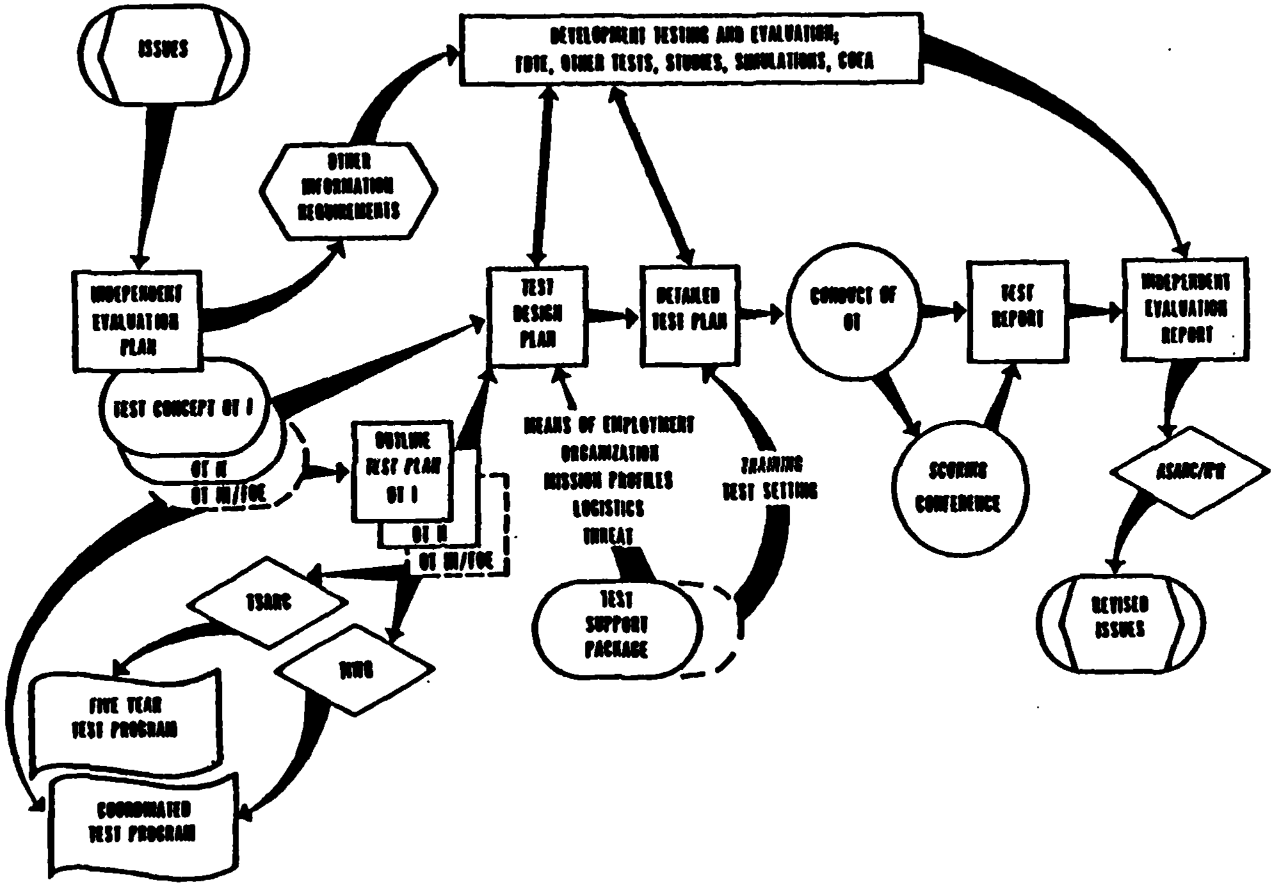

FIGURE B-3. OPERATIONAL TEST AND EVALUATION PROCESS

After the test has been conducted, the test organization reports the conditions under which the test was run and the data results. The test reports are limited to findings of fact, including such summary calculations as are called for in the test design plan, but do not draw inferences, make recommendations, or advance evaluative judgements. The designated independent evaluator reports a conclusion for each operational issue of the test with due consideration to any relevant criteria which may exist, along with an evaluation of the adequacy and validity of the operational test. The conclusion as to operational effectiveness of the evaluated system or item contained in the Independent Evaluation Report (IER) is based on data from all sources including DT, OT, FDTE, studies, simulations, and analysis, and takes into account the validity and relevance of each datum source. The operational IER, then, is supplied as one of several documents directly to the ASARC for their consideration. The decision resulting from the ASARC is the basis for revising the operational issues and repeating the cycle, unless the decision is the final one in the acquisition cycle.

B.3.3 Life Cycle System Management Model

The LCSMM is an event-step process by which Army materiel systems are initiated, validated, developed, deployed, supported, modified, and disposed. Promulgated in DA Pamphlet 11-25,[15] the LCSMM summarizes and organizes the requirements of AR 1000-1 and its supporting regulations and circulars.

Unfortunately, the LCSMM has not been revised since 1975, making it considerably out of date. This paragraph provides an overview of an updated LCSMM from program initiation until the production and deployment decision. The emphasis is placed on personnel and training related events. Figure B-4 illustrates the LCSMM.

B.3.3.1 Program Initiation (Milestone 0)

As part of its mission, TRADOC conducts continuing analyses of mission areas to identify requirements for enhanced capabilities. When a mission need is identified, TRADOC, in coordination with

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15 DA Pamphlet 11-25, Life Cycle System Management Model for Army Systems. HQDA: May 1975.

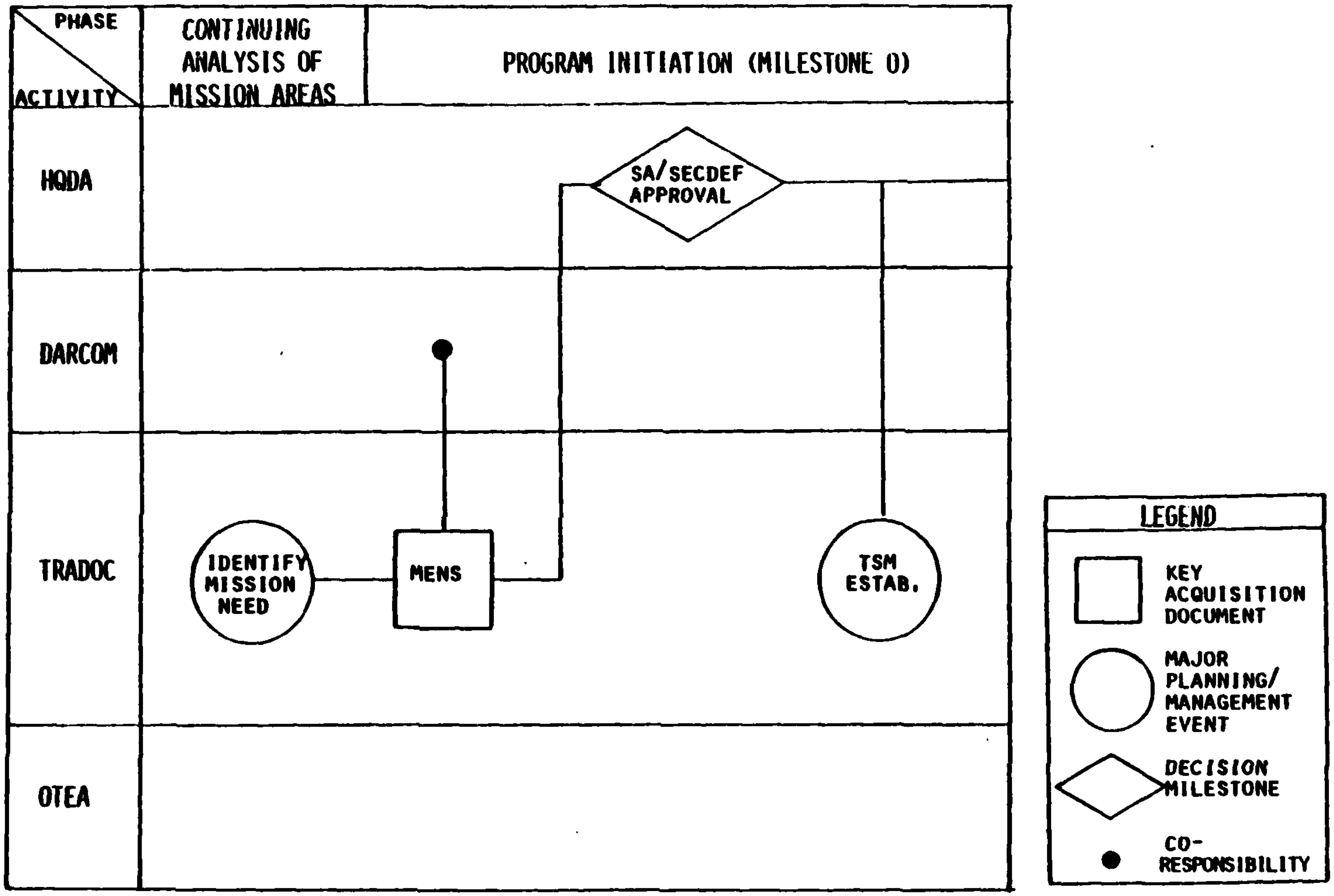

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 1 OF 11)

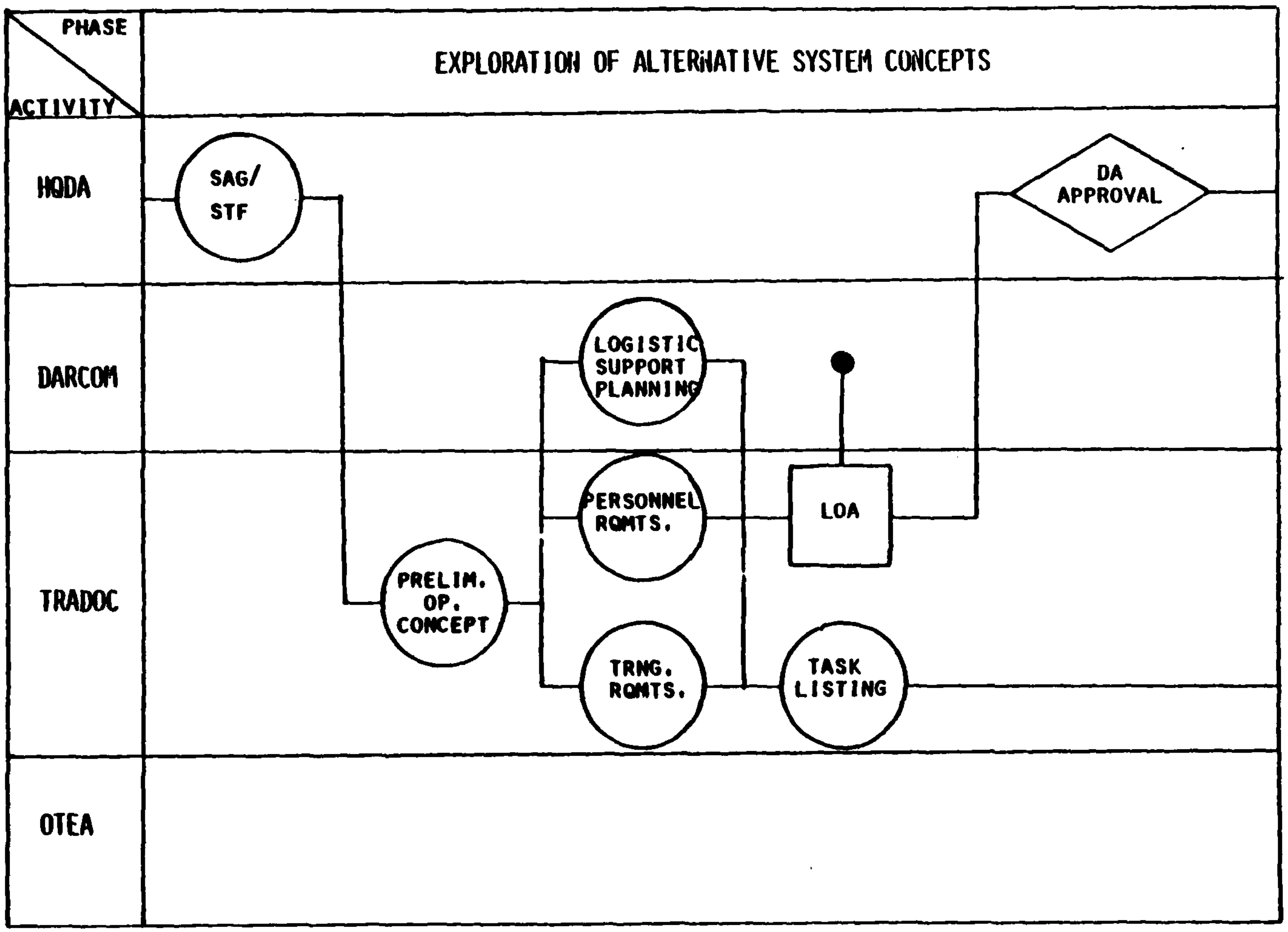

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 2 OF 11)

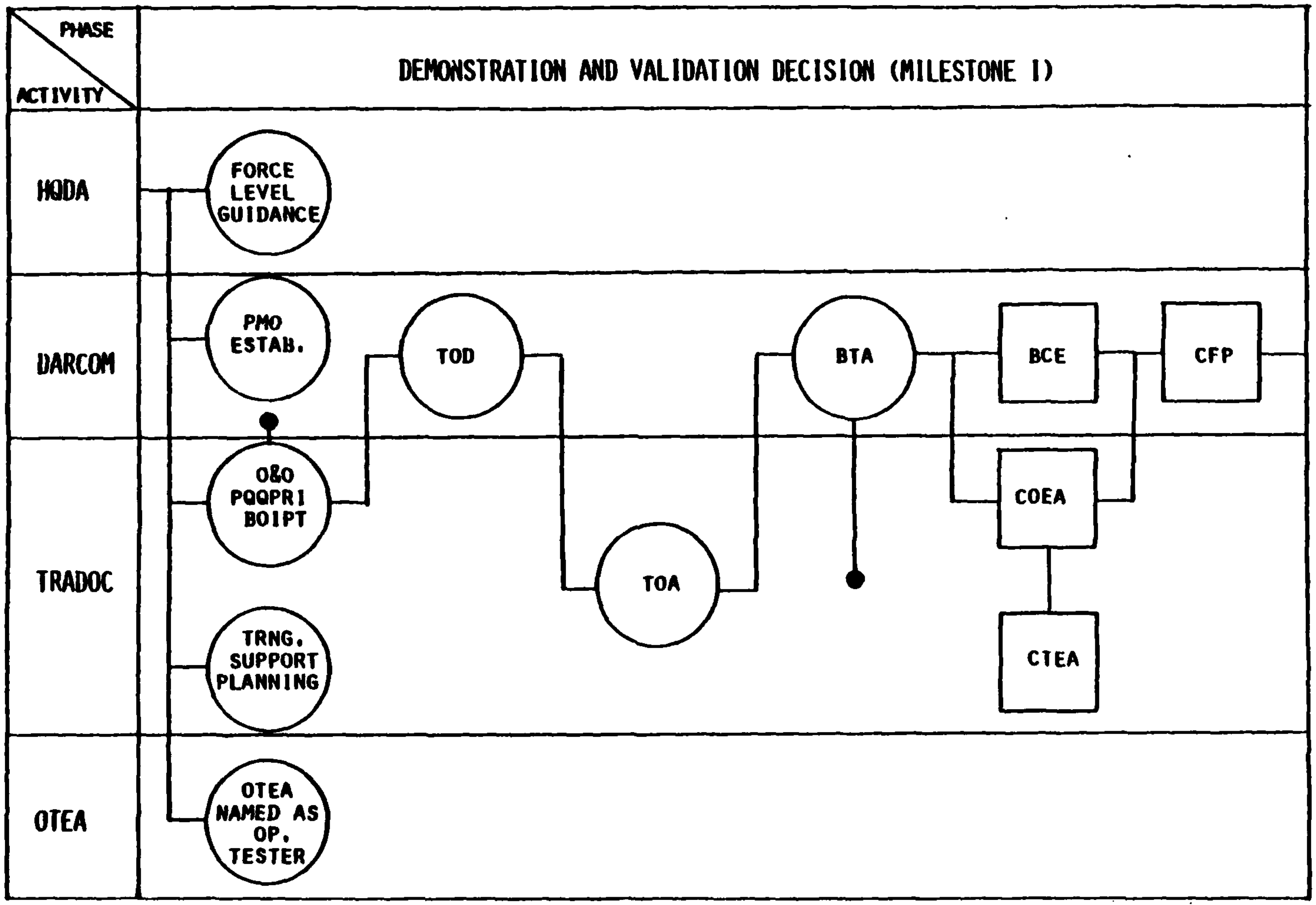

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 3 OF 11)

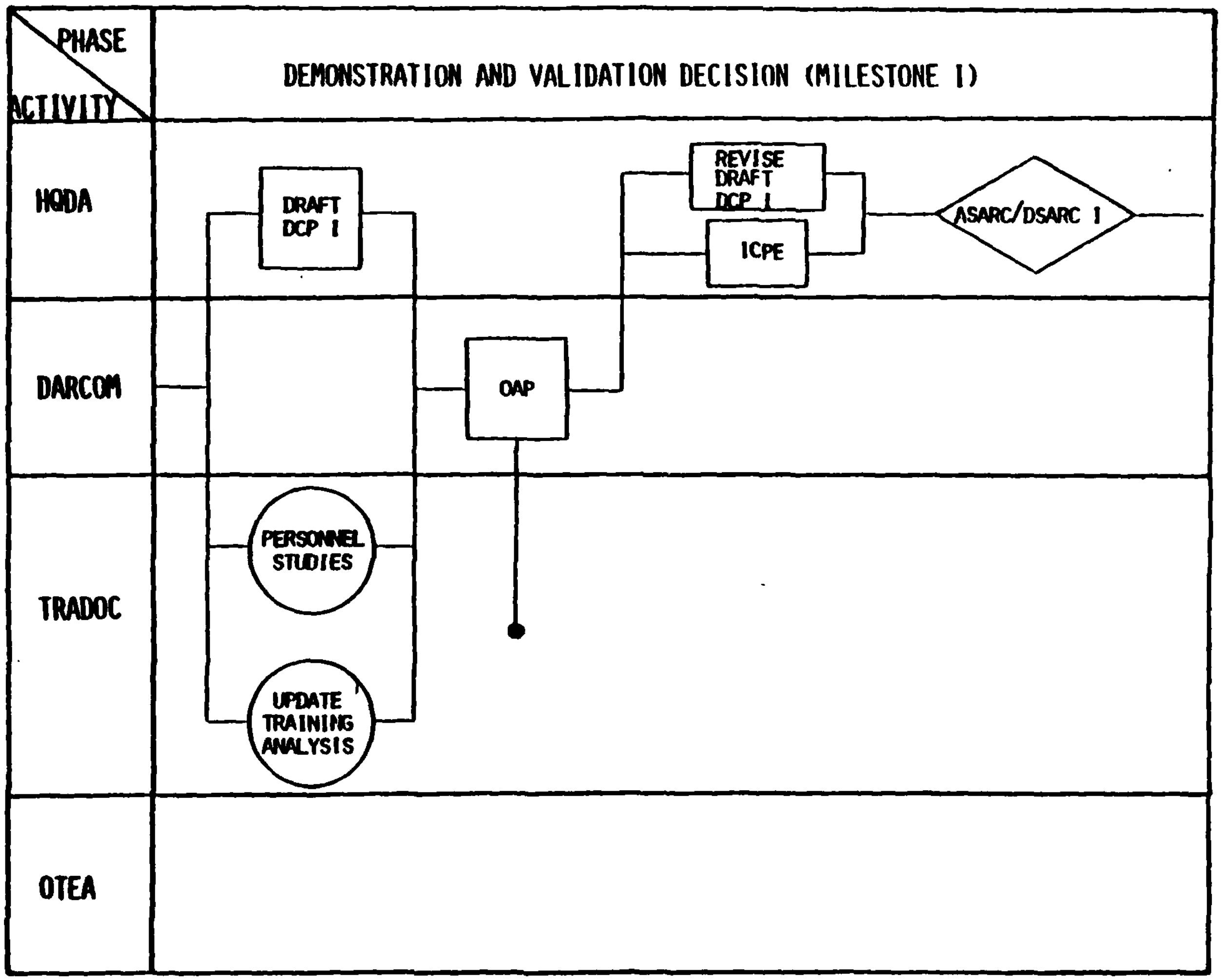

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 4 OF 11)

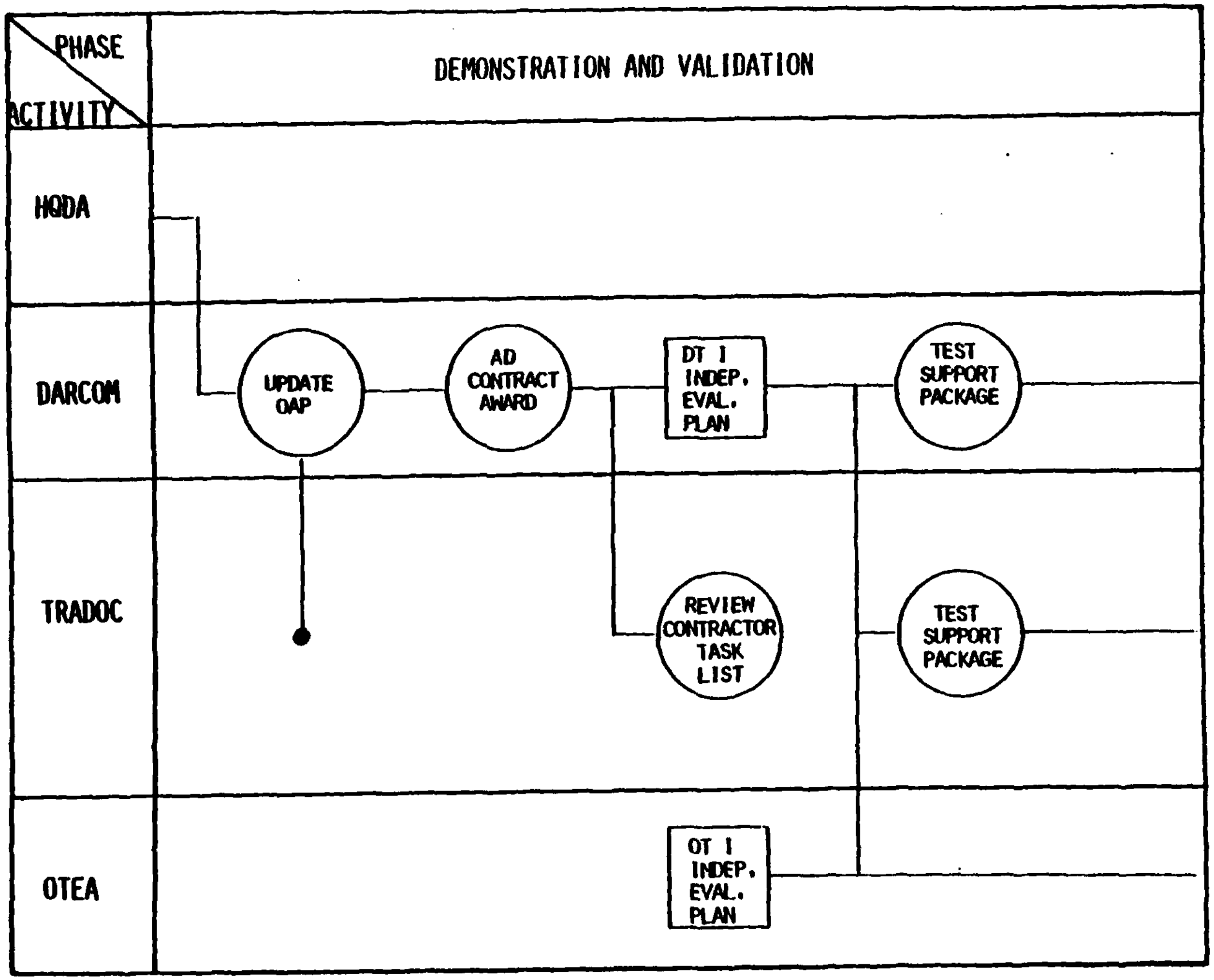

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 5 OF 11)

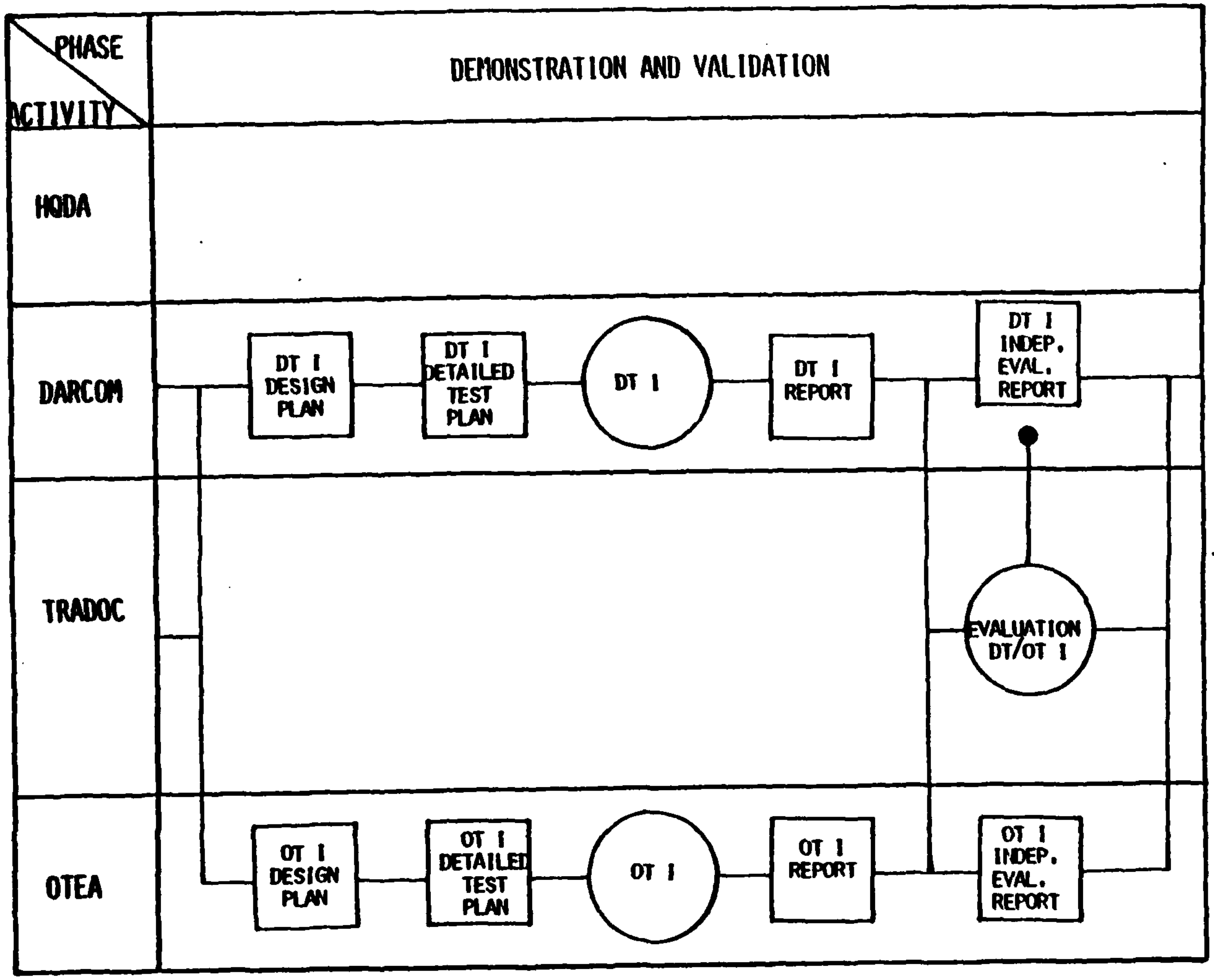

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 6 OF 11)

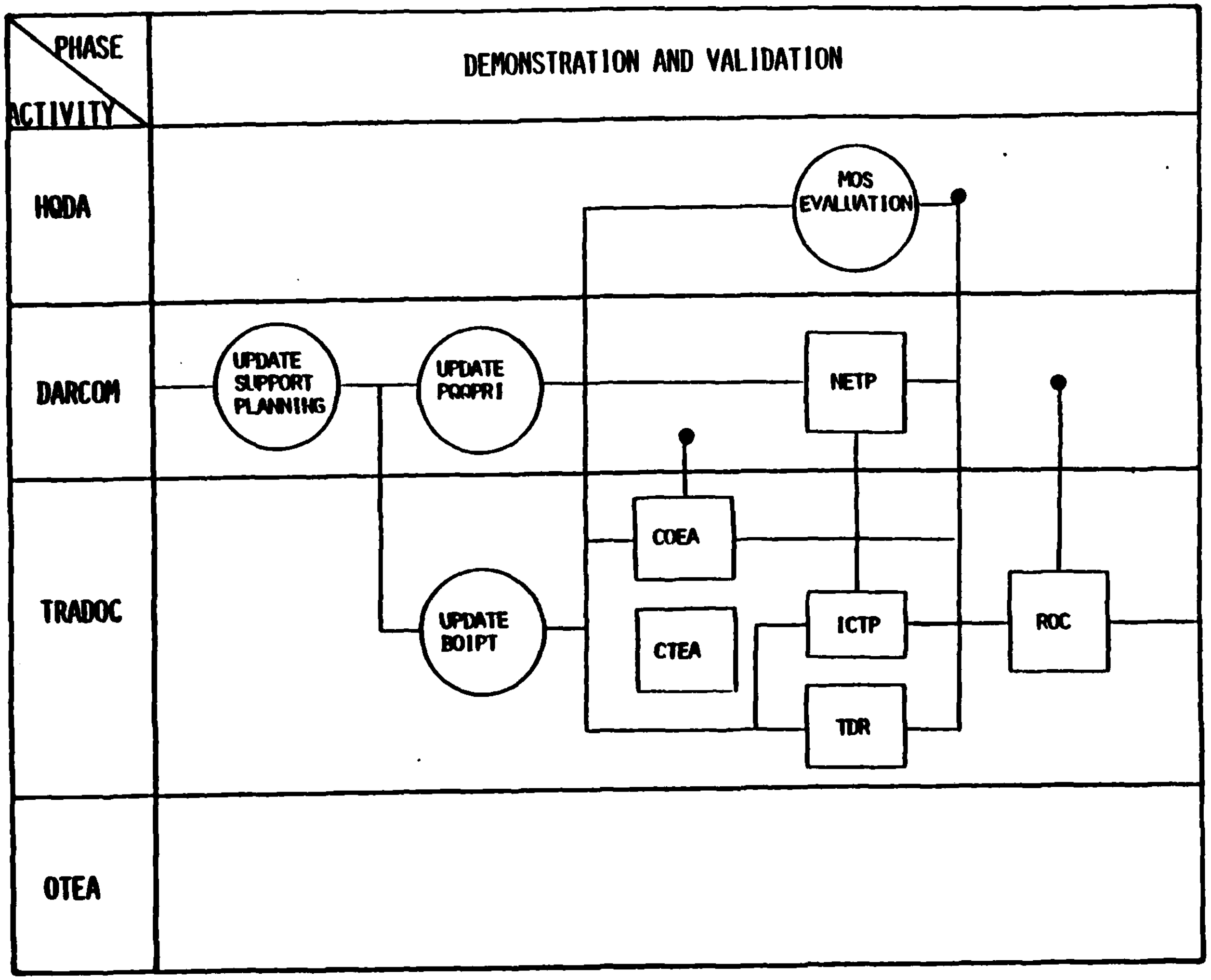

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 7 OF 11)

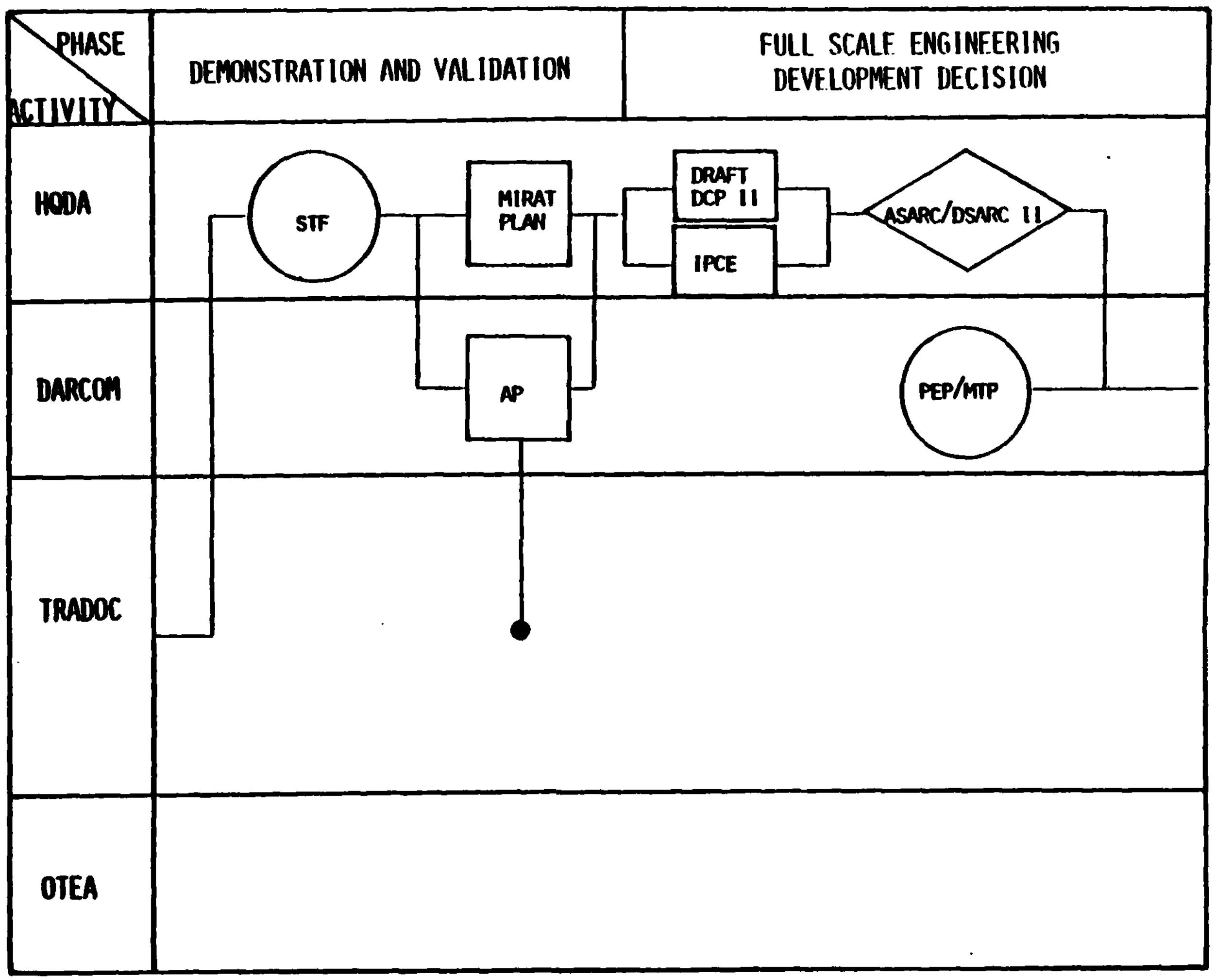

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 8 OF 11)

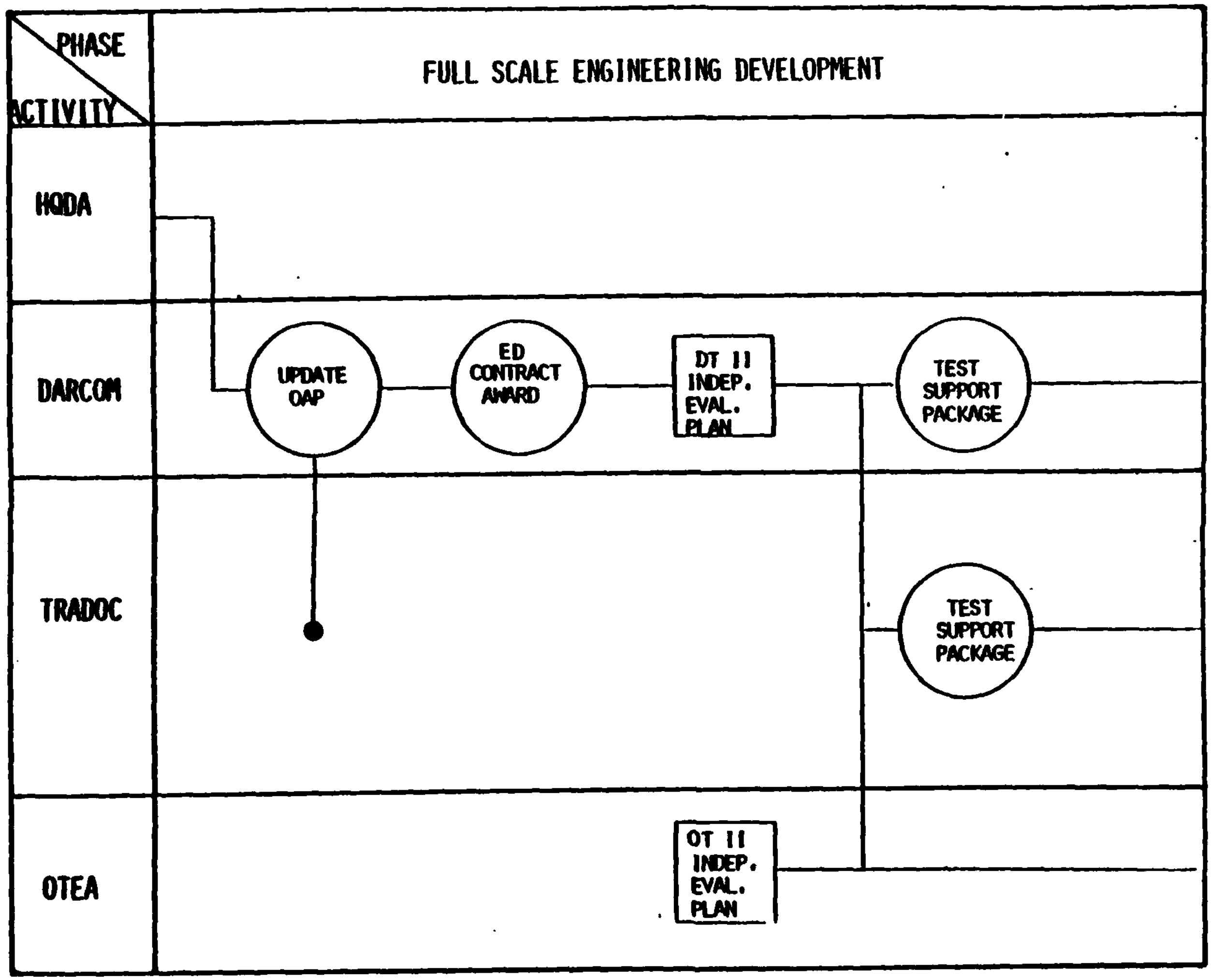

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 9 OF 11)

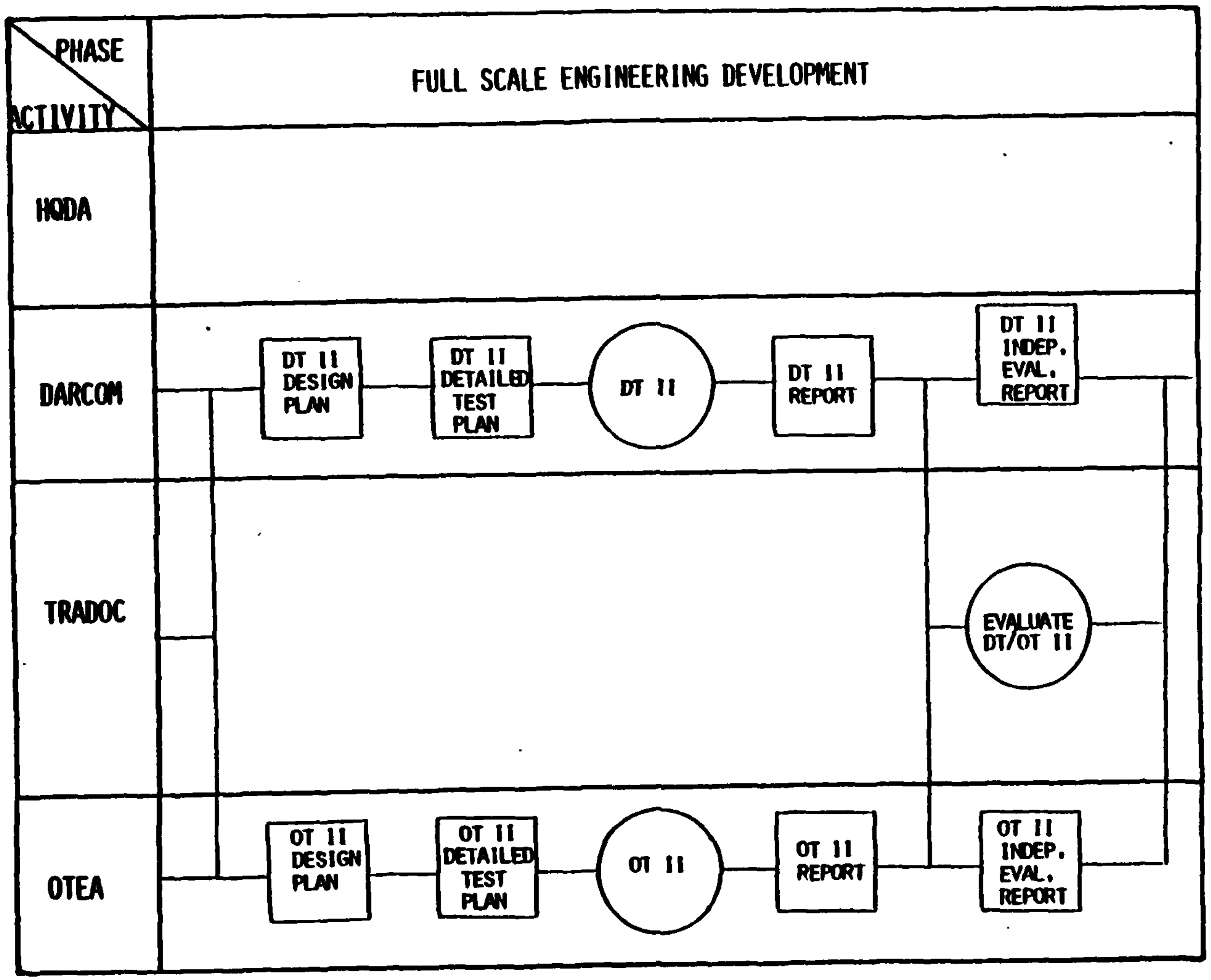

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 10 OF 11)

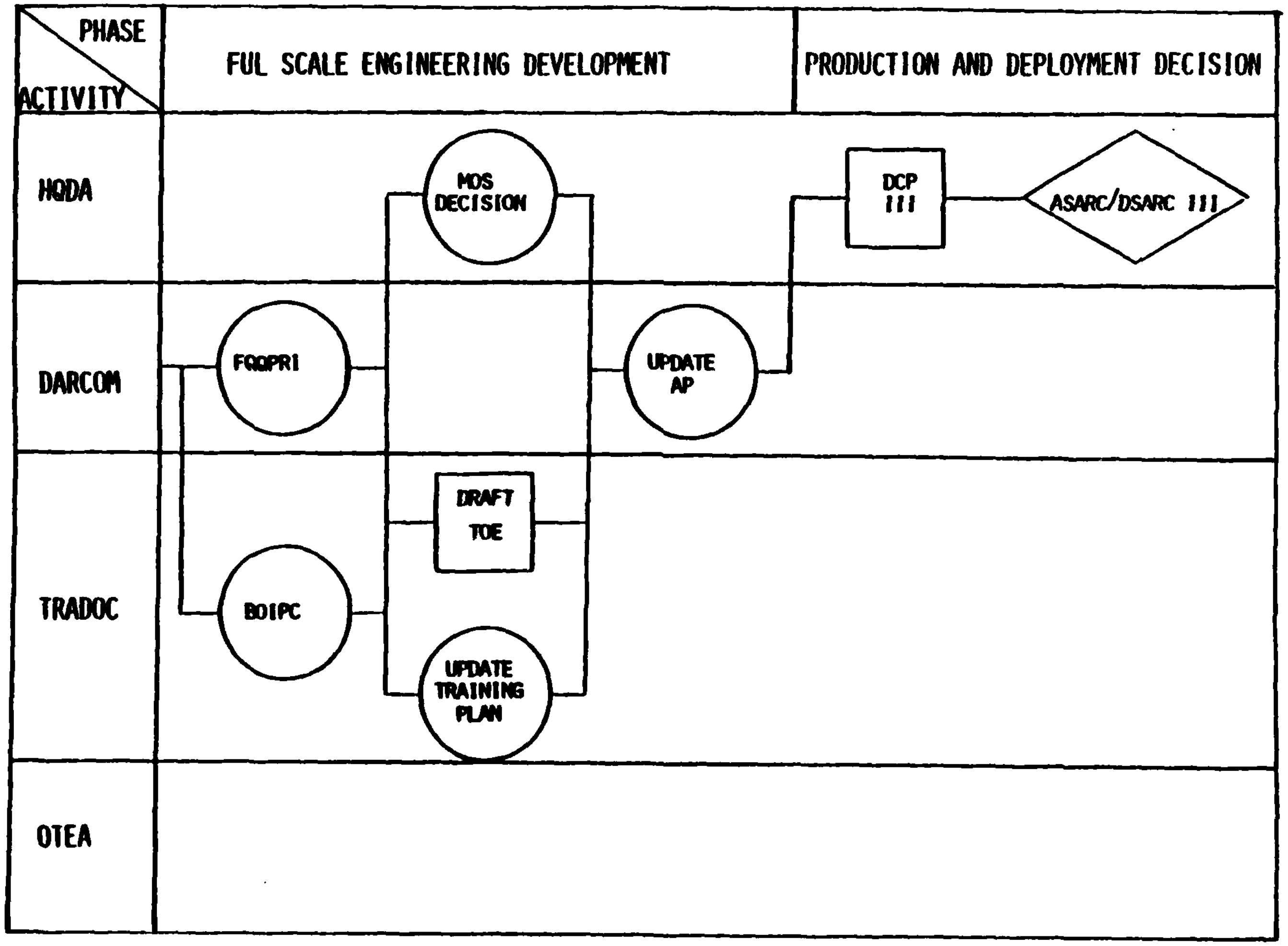

FIGURE B-4. LIFE CYCLE SYSTEM MANAGEMENT MODEL (PART 11 OF 11)

DARCOM, prepares a MENS. The MENS will describe the operational task to be accomplished and will not be cast in terms of capabilities and characteristics of a hardware or software system.

B.3.3.2 Exploration of Alternative System Concepts Phase

The purpose of the second phase is to explore and identify alternative system concepts selected from all available sources. This exploration will generally be undertaken by a STF under DCSOPS direction or by a Special Study Group (SSG) chartered by CG, TRADOC. A Study Advisory Group (SAG) will generally be used in conjunction with an STF or SSG.

At the time of the materiel concept investigation, "personnel" is addressed only in very general terms. The TRADOC proponent may investigate at a very general level the impact of the materiel concept upon recruiting, MOS structure, training, and manpower authorizations. Questions such as the following must be asked and eventually answered:

- Can it reasonably be assumed that soldiers with the required mental and physical skills will be recruited and made available to operate and maintain the proposed system?
- Will current or future manpower authorizations support the system?
- What will be the impact on the current personnel structure?
- Will personnel trade-offs be required? What will be the effect on proposed system objectives?
- What is the human resources development impact of the proposed system?
- What cost-effective trade-offs are possible to capitalize on the human resources aspects for the system instead of materiel aspects?

When a concept has been formulated, the combat and training developers should begin planning the training/training device

requirements for the conceptualized system. These requirements can only be stated in general terms; however, the planning must proceed at the earliest possible time since training requirements can (theoretically) influence materiel design. The first element of the requirements is a Task and Skill Analysis (TASA), based on the concept of the materiel. The TASA should answer the question, "What is the best allocation of functions among operations, maintenance, and materiel?" Following the completion of the rough TASA, there should be an assessment of the general training/training device requirements.

A general statement of personnel requirements can then be addressed:

- Individual skills and skill levels required
- Estimate of the number of personnel required to operate and maintain the system
- Unique physical and mental considerations.

TRADOC, in coordination with DARCOM, prepares a Letter of Agreement (LOA) for HQDA approval. The LOA is the requirements document which supports the Demonstration and Validation (DVAL) phase.

Concurrent with the preparation of the LOA, the rough TASA is analyzed and subdivided into three categories: machine functions (or those which the developer believes could be best performed by the hardware), shared functions (man-machine interface), and purely human tasks. From the latter two categories, critical tasks are identified (as defined in TRADOC Pamphlet 350-30).[16] These critical tasks are those most likely to require formal training and will serve as guidelines for developing the training support plan.

B.3.3.3 Demonstration and Validation Decision (Milestone I)

With the approval of the LOA, formulation of a system concept and an acquisition strategy is initiated. The Secretary of the Army charters a PM who reports through a DARCOM commodity command. OTEA is

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[16] TRADOC Pamphlet 350-30. Interservice Procedures for Instructional Systems Development. Fort Monroe, VA: 1 August 1975.

named as the operational tester, while DCSOPS issues force level guidance to the major commands.

The PM must identify to the proponent any organizational equipment, training, and personnel trade-offs that would be required if the system is added to the total force structure. This information will be used by TRADOC to develop, in coordination with the PM, the organizational and operational concepts which will be incorporated in the Concept Formulation Package (CFP) and also form the basis for the Provisional QQPRI and the first Basis of Issue Plan (BOIP).

Training support planning is focused toward considerations that will influence the design of the materiel and proposed training devices. These considerations may influence trade-offs required in later events. The basic document for planning is the outline Individual and Collective Training Plan (ICTP). As development progresses, the ICTP is updated and modified as needed. As more is known about system training requirements, the trainer develops plans for training methods, programs, and media; training devices; systems hardware for training; and scheduling requirements for training user and support personnel.

The CFP provides for the evaluation of alternative concepts and selection of the best concepts as a coordinated combat developer and materiel developer effort. The CFP consists of a Trade-off Determination (TOD), a Trade-Off Analysis (TOA), a Best Technical Approach (BTA), and a preliminary Cost and Training Effectiveness Analysis (CTEA) and Cost and Operational Effectiveness Analysis (COEA). The TOD is conducted by the PM and includes alternative personnel support concepts, together with the advantages and disadvantages of each, for each design alternative. Upon completion, the TOD is furnished to TRADOC. The TOA of the concepts identified in the TOD is conducted by TRADOC and is returned to the PM. The BTA is jointly prepared by TRADOC and the PM and describes the optimum contribution of an operational support concept for further development and evaluation during the validation and full scale development of the item. The CTEA/COEA is conducted by TRADOC and addresses the effectiveness of, among other things, the personnel support concept in terms of operational availability.

The PM, in coordination with TRADOC, OTEA, and LEA, will prepare an Outline Acquisition Plan (OAP), which presents the acquisition strategy through system demonstration and validation. The Organizational and Operational Concept (O&O), the Coordinated Test

Program (CTP), and plans for technical development, management, finance, personnel and training requirements, and logistic support.

In preparation for the DSARC decision to proceed with demonstration and validation, HQDA prepares the DCP I, the IPS I, and an Independent Parametric Cost Estimate (IPCE). The ASARC I formulates the Army's position for the Secretary of the Army's approval. The DSARC I formulates the DoD position for the Secretary of Defense's approval.

B.3.3.4 Demonstration and Validation Phase

Based on ASARC/DSARC I guidance, the OAP is updated by the PM in preparation for the award of Advanced Development (AD) contracts. The philosophy of OMB Circular A-109 calls for multiple awards to enhance cost-effectiveness through competition.

When the PM prepares the Request for Proposal (RFP), TRADOC must ensure that the proposed contracts contain the basic critical personnel criteria required for operation and maintenance. This includes the outputs from all previous investigations and events. The primary concern is development of hardware that the average soldier can effectively operate and maintain. Constraints based on previous personnel planning must be part of the contracts.

A specification of the Advanted Development contracts must be that the contractor(s) furnish as early as possible data for a TASA for each proposed operator and maintainer. Their analysis will be used for planning training requirements (updating ICTP), planning MOS requirements, and developing test issues for DT/OT I.

Using the contractor furnished TASA, TRADOC, in concert with the PM must determine critical tasks, evaluate training and training device requirements for the tasks, and make an initial estimate of whether the operator and maintainer will require new MOSs or modification of existing MOSs.

The documentation for the DT/OT I cycle is then prepared. The basis for testing is the CTP of the OAP. It is structured to ensure tasks associated with the hardware are tested and/or evaluated. These include all operational, maintenance, and support tasks that are required to make the system effective. Each task must be identified and an estimate made for the time required for performance. The man-machine interface of mental and physical requirements for the soldier

expected to operate and maintain the system must be tested also. TRADOC prepares the personnel support input to the TSP and forwards it to the PM to be used in the preparation of the DT TDP and to the test organization to be used in the preparation of the OT TDP.

After DT/OT I has been completed and the test reports prepared, the proponent, in coordination with the PM, must evaluate the results. The operation and maintenance task lists must be reviewed and verified. The personnel criteria that were specified in the test issues should be reviewed and revised if necessary. From the preceding actions, the outline training plan can be updated, the issues for further test developed, and the basic information for an updated QQPRI accumulated.

The DARCOM NET element and TRADOC refine training requirements for operator and logistic personnel based on the outputs of DT/OT I and any other new personnel training requirements determined in previous or ongoing investigations. They also analyze technical documentation to determine personnel and training impact and plan participation in, and attendance at, the staff planners course, the technical orientation course, and the instructor and key personnel course. The updated training planning will be documented by the materiel developer and should include a description of training devices, training methods and media, training extension courses, soldiers and commanders manuals, skill qualifications tests, ICTP material, field manuals, and other requirements necessary to provide for individual and unit training.

DARCOM elements will revise the QQPRI and send it through US Army Materiel Readiness Support Activity (MRSA) to TRADOC. The TRADOC approved QQPRI input will be returned to MRSA for further action and forwarding to MILPERCEN.

Initial unit structures are revised by TRADOC proponent schools/agencies using combat developer studies, QQPRI, and BOIP feeder data. The DARCOM proponent command provides feeder data through the Equipment Authorization Review Agency to TRADOC, who will task the proponent school to revise the BOIP to reflect any changes.

TRADOC will conduct a COEA of the system. As part of this effort, a CTEA will be conducted on the training subsystem.

The materiel developer is responsible for the initiation, development, and publication of the New Equipment Training (NET) Plan.

TRADOC will assist by providing input as applicable to MOS training prior to formal review/update at the Training and Support Work Group (TSWG) meetings. TRADOC schools will actively participate (throughout the life cycle) in the DARCOM sponsored TSWGs. DARCOM will prepare elements of the ICTP for which it has functional responsibility and forward it to TRADOC for inclusion in the ICTP. The designated TRADOC proponent develops the respective individual and collective training plans based upon QQPRI, task analysis, CTEA, and materiel developer input. In addition to milestone schedules, the ICTP should include training concepts, estimated training class quotas by MOS and skill levels, a description of required training literature, training extension course listings, audio-visual media, simulators, training devices, and hardware requirements for conducting institutional instruction.

TRADOC is responsible for the development of the Required Operational Capability (ROC). The ROC will include a personnel assessment that will identify personnel considerations which have an impact on further full-scale development of the materiel system and personnel support. TRADOC will ensure that the ROC includes:

- Personnel interface with existing and projected equipment

- Training and training device requirements

- Desired system safety and human engineering characteristics.

The STF or SSG may be reconvened to review the progress of the program in preparation for the next DSARC decision.

A MIRAT Plan is prepared by MILPERCEN and coordinated with the Recruiting Command.

The PM prepares the Acquisition Plan (AP) in coordination with TRADOC. The AP presents the acquisition strategy through FSED. The AP should include identification of new skills, individual and crew training requirements. Skill Performance Aids (SPA), training devices, training facilities, and associated schedules.

B.3.3.5 Full-Scale Engineering Development Decision (Milestone II)

In preparation for ASARC/DSARC II, a DCP II, IPS II, and an updated IPCE are prepared. The Secretary of Defense's approval initiates the Full-Scale Engineering Development (FSED) phase.

The PM prepares for future production by Producibility Engineering and Planning (PEP) and a Manufacturing Methods and Technology Program (MTP).

B.3.3.6 Full-Scale Engineering Development Phase

FSED is initiated with the award of the Engineering Development (ED) contract. While the ED model is being developed, DT/OT II is revised and refined planning begins. Major emphasis is placed on demonstrating during the DT/OT II phase that all key criteria which have been established for the system can be satisfied, including training requirements and personnel supportability. DT II must be carefully planned to provide an adequate assessment of training and personnel and minimize associated risks. OT II must validate the suitability of personnel support and training (to include training devices). The operational tester prepares a TDP which identifies the test objectives for materiel being tested during OT II. Personnel input to the TDP will provide for a comprehensive evaluation of system supportability, doctrine, organizational procedures, and user training in accordance with the approved personnel support concept. TRADOC provides test issues, associated criteria, and the combat developer/trainer test support packages to the test organization. The package includes statement of organization and basis of issue, training plan, and statement of personnel support concepts. Action must be taken to identify and stabilize personnel for the test.

Instructors, schooled by a selected contractor, will train key operator and support personnel for the conduct of OT II using the TRADOC-approved training program to be implemented when the system is approved for deployment. Normally, SPA materiel should be available for their training also.

Following completion of DT/OT II, the responsible test agencies prepare test reports. These reports contain the data obtained and the conditions which actually prevailed during test execution. The test reports also contain an analysis of the personnel test results versus the personnel test objectives. OTEA prepares an IER based upon the OT report, studies and other appropriate sources, to include the DT report. When determining the military worth of the equipment personnel aspects as well as operational aspects are considered. Potential personnel problems, training, organizational and doctrinal implications, and the impact of fielding or not fielding the equipment are some of the factors considered. The IER, together

with test reports and supporting documentation (comments from other agencies, etc.), are provided to the DSARC/ASARC members at least two weeks prior to the preliminary review. The data contained in these documents should assist the decision makers in reaching a valid and reasonable decision.

The final QQPRI is developed by the materiel developer approximately thirty months prior to scheduled deployment of new materiel items. Some considerations of the proponent school/agency, while coordinating with other interested schools/agencies, are:

- Are all system components and subcomponents identified and listed in QQPRI documentation, to include MOS and annual maintenance man hours for each level of maintenance?

- Is the MOS proper to support equipment in the proposed Table of Organization and Equipment (TOE)?

- Are skill levels correct for the MOS and expertise required?

- Will training be sufficient to provide required expertise?

- Will there be a sufficient number of MOS trained personnel in the field to support the equipment?

Based on data from OT II, the proponent makes any changes in the unit structure for the new system and incorporates them into the BOIP. Normally, an update of BOIP incudes planned changes in other equipment and in personnel necessary to accommodate new items of equipment.

TRADOC will continue to update training planning to validate personnel training requirements. The training plan will be expanded and revised in preparation for initiation of resident training. Test reports of DT I/OT I, DT II/OT II will be used to provide information on the use and effectiveness of training personnel. If not previously provided, proponent schools will take action to obtain logistical support analysis requirements (LSAR) output summary sheets from the materiel developer. Draft equipment publications, LSAR summaries, and

field manuals will be evaluated to ensure correlation of training with personnel support doctrine and organizational structure of support units. This update training plan will be evaluated during OT II or III, if these tests are required.

The PM, in coordination with TRADOC, updates the AP in preparation for the final ASARC/DSARC review.

APPENDIX C

LIST OF ACRONYMS

ACB	Army Classification Battery
AD	Advanced Development
AFSC	US Air Force Systems Command
AIT	Advanced Individual Training
ALARM	Alerting Long Range Radar for Moving Targets
AMSAA	US Army Materiel Systems Analysis Agency
AMMH	Annual Maintenance Man-Hours
AO	Action Officer
AOS	Add-On Stabilization
AP	Acquisition Plan
AR	Army Regulation
ARI	US Army Research Institute for the Behavioral and Social Sciences
ARTADS	Army Tactical Data Systems
ARTOC	Army Tactical Operations Center
ASARC	Army Systems Acquisition Review Council
ASD(MRA&L)	Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics)
ASI	Additional Skill Identifier
ASIC	All-Source Intelligence Center
AVCSA	Assistant Vice Chief of Staff, Army
BESRL	Behavioral Sciences Research Laboratory
BDE	Brigade
BDMSC	BDM Services Company
BOIP	Basis of Issue Plan
BTA	Best Technical Approach
CAC	US Army Combined Arms Center
CAPS	Computer Aided Programming System
C^2	Command and Control
C^3I	Command, Control, Communication, and Intelligence
CDB	Consolidated Data Base
CDEC	US Army Combat Developments Experimentation Command
CECOM	US Army Communications-Electronics Command
CFP	Concept Formulation Package
CGSC	US Army Command and General Staff College
CHRT	Coordinated Human Resource Technology
COEA	Cost and Operational Effectiveness Analysis

COFT	Conduct of Fire Trainer
CP	Command Post
CRT	Cathode Ray Tube
CSA	Chief of Staff, Army
CTEA	Cost and Training Effectiveness Analysis
CTP	Coordinated Test Program
DA	Department of the Army
DARCOM	US Army Materiel Development and Readiness Command
DCC	Division Computer Center
DCP	Decision Coordinating Paper, or Development Concept Paper
DCSLOG	Deputy Chief of Staff for Logistics (HDQA)
DCSOPS	Deputy Chief of Staff for Operations and Plans (HQDA)
DCSPER	Deputy Chief of Staff for Personnel (HQDA)
DCSRDA	Deputy Chief of Staff for Research, Development and Acquisition (HQDA)
DDR&E	Director, Defense Research and Engineering
DEVTOS	Developmental Tactical Operations System
DIV ARTY	Division Artillery
D/K/P	Display/Keyboard and Printer
DoD	Department of Defense
DoDD	DoD Directive
DoDI	DoD Instruction
DPM	Deputy Project Manager
DS	Direct Support
DSARC	Defense Systems Acquisition Review Council
DT	Developmental Test
DTOS	Division Tactical Operations System
DT&E	Developmental Test and Evaluation
DVAL	Demonstration and Validation
ECOM	US Army Electronics Command
ECSL	Extended Continuous Simulation Language
ECS^2	Executive/Control/Subordinate System
ED	Engineering Department
EUROTOS	European Tactical Operations System
FDTE	Force Development Test and Evaluation
FEBA	Forward Edge of the Battle Area
FIST	First Intelligence Simulation Test
FORSCOM	US Army Forces Command
FSED	Full Scale Engineering Development

GAO	General Accounting Office
GS	General Support
HEL	US Army Human Engineering Laboratory
HFE	Human Factors Engineering
HFEA	Human Factors Engineering Analysis
HRD	Human Resources Data
HRDT	Human Resources in Design Trade-Offs
HSC	US Army Health Systems Command
ICTP	Individual and Collective Training Plan
IEP	Independent Evaluation Plan
IER	Independent Evaluation Report
I^2	Interim-Interim
IPCE	Independent Parametric Cost Estimate
IPS	Integrated Personnel Summary
ISD	Instructional Systems Development
ITDT	Integrated Technical Documentation and Training
JGD	Job Guide Development
LCOM	Logistics Composite Model
LCSMM	Life Cycel System Management Model
LEA	US Army Logistics Evaluation Agency
LOA	Letter of Agreement
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Record
M	Maintainability
MAP	Manpower Analysis Plan
MASSTER	Modern Army Selected Systems Test, Evaluation, and Review
MENS	Mission Element Need Statement
MIOD	Message Input/Output Device
MILPERCEN	US Army Military Personnel Center
MIRAT	MILPERCEN Initial Recruit and Training
MMM	Maintenance Manpower Modeling
MOS	Military Occupational Skill
MRDC	US Army Medical Research and Development Command
MRSA	US Army Materiel Readiness Support Activity
MTBF	Mean-Time-Between-Failure
MTI	Moving Target Indicator
MTP	Manufacturing Methods and Technology Program
NBC	Nuclear, Biological, and Chemical
NET	New Equipment Training

OAP	Outline Acquisition Plan
OFPP	Office of Federal Procurement Policy
OMB	Office of Management and Budget
OPM	Office of the Project Manager
OSD	Office of the Secretary of Defense
OSUT	One Station Unit Training
OT	Operational Test
OTEA	US Army Operational Test and Evaluation Agency
OTP	Outline Test Plan
OT&E	Operational Test and Evaluation
O&O	Organizational and Operationsl
PEP	Producability Engineering and Planning
PM	Project Manager
PMO	Project Management Office
PT/ME	Physical Teardown/Maintenance Evaluation
QQPRI	Qualitative and Quantitative Personnel Requirements Information
R	Reliability
RFP	Request for Proposals
ROC	Required Operational Capability
RTO	Radio Telephone Operator
SAG	Study Advisory Group
SAI	Science Applications, Inc.
SAT	Systems Analysis of Training
SATOS	Seventh Army Tactical Operations System
SES	Systems Engineering Study
SIGINT	Signal Intelligence
SIMTOS	Simulated Tactical Operations System
SOC	System Ownership Cost
SOTAS	Stand-Off Target Acquisition System
SOW	Statement of Work
SPA	Skill Performance Aids
SPC	Systems Planning Corporation
SQI	Special Qualification Index
SS	System Safety
SSG	Special Study Group
STF	Special Task Force
STO	Search and Track Operator
TAC CP	Tactical Command Post
TACFIRE	Tactical Fire Control System

TACOM	US Army Tank-Automotive Command
TASA	Task and Skill Analysis
TCS	Tactical Computer System
TCT	Tactical Computer Terminal
TDP	Test Design Plan
TDR	Training Device Requirement
TM	Technical Manual
TOA	Trade-Off Analysis
TOD	Trade-Off Decision
TOE	Table of Organization and Equipment
TOS	Tactical Operations System
TOS^2	Tactical Operations System Operable Segment
TP	Test Plan
TRADE	Training Devices
TRADOC	US Army Training and Doctrine Command
TSM	TRADOC System Manager
TSS	Target Surveillance Supervisor
TSP	Training Support Package
TSWG	Training and Support Working Group
T&E	Test and Evaluation
U-COFT	Unit Conduct of Fire Trainer
UIOD	User Input/Output Device
USAEUR	US Army, Europe
USD(RE)	Under Secretary of Defense (Research and Engineering)
UTM	Universal Transverse Mercator
VCSA	Vice Chief of Staff, Army